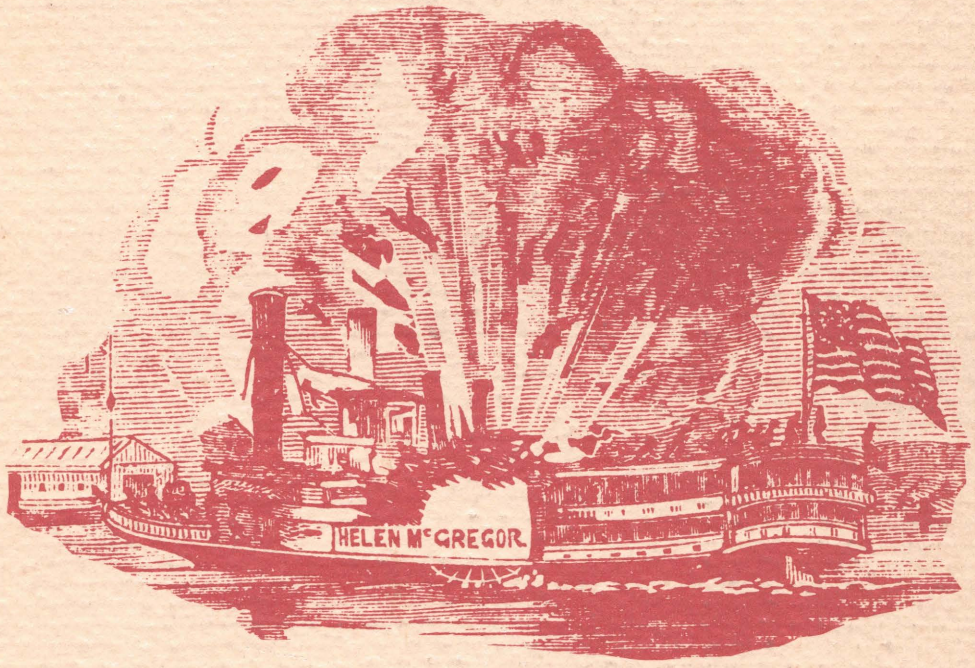
EARLY RESEARCH AT THE FRANKLIN INSTITUTE



THE INVESTIGATION INTO THE CAUSES OF STEAM BOILER EXPLOSIONS

1830-1837

EARLY RESEARCH AT THE FRANKLIN INSTITUTE

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REPORT

ON THE

EXPLOSIONS OF STEAM BOILERS.

FRANKLIN INSTITUTE:

1836.

EARLY RESEARCH AT THE FRANKLIN INSTITUTE

THE INVESTIGATION INTO THE CAUSES OF STEAM BOILER EXPLOSIONS 1830-1837

By BRUCE SINCLAIR
Assistant Professor of History, Kansas State University

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AUTHOR'S PREFACE

The Franklin Institute's boiler explosion investigation was clearly the most outstanding scientific accomplishment in the organization's early history. It involved a brilliant group of young scientists who would later go on to important careers and national reputation. The research also set the direction of the Institute's future development. The experiments were thoughtfully planned and skillfully executed. No better example could be chosen to reflect the organization's significance in the history of American science and technology.

When the director of the Institute's research laboratories began to think of a history which might be used to commemorate the dedication of their new research facility, the boiler explosion investigation was an easy and natural choice of subject matter. It also seemed perfectly appropriate for the occasion to reprint Alexander Dallas Bache's *General Report on the Explosions of Steam Boilers*, with an introduction and a summary of the investigation's significance. Re-publication makes this important historical document more readily available and introduces the general reader to a surprisingly sophisticated piece of research, conducted at a time when elaborate experimentation was the exception rather than the rule.

Several libraries and individuals contributed to my research and I am pleased to acknowledge their aid. The beginning for any research on the Institute is clearly its own library and archives. The Institute's library is one of the great treasure-houses for historians of American science and technology. John McGowan and his staff were generous and helpful well beyond the normal limits of duty. I should also like to record the courtesy of the staff of the American Philosophical Society Library, the Historical Society of Pennsylvania, and of the National Archives in Washington, D. C. I am particularly obligated to Sam Suratt, Archivist of the Smithsonian Institution, for helping to track down Joseph Henry's analysis of the Bache report which was published in London in 1837.

B. S.

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FOREWORD

October 19, 1966. On this day, we dedicate the new research center of The Franklin Institute Research Laboratories.

The celebration of a special event in the life of an institution, such as this is, presents a compelling opportunity to commemorate earlier events of signal character, events that stand out above others in the sweep of history.

Thus we were compelled, as we prepared to dedicate this magnificent new research facility, to scan back over the 142 years of Franklin Institute history—a history studded with events that have given the Institute a special stature in the realm of science and education. Events such as establishment of one of the first "mechanics' institutes" in America; the first public high school in the nation; the first geological survey of Pennsylvania; standards for weights and measures and screw threads, which are still in effect; and scientific investigations in a great many fields.

Our quest through Institute history was guided by the urge to be useful, a tradition that our founders envisaged as most richly embodied in our namesake, Dr. Franklin. A publication, we felt, exploring in detail an element of our past that might serve scholars and historians, would have the virtue of long-term utility. Not only would such a book serve as a relevant and fitting memento of the dedication of the Institute's most modern scientific establishment, but it could continue to function, in universities and libraries throughout the country, as an artifact of New World culture and technology, and a lasting resource for scholars.

It was our good fortune to discover, through Dr. Feldmeier, the Director of our Research Laboratories, and his colleagues at the American Institute of Physics, that Mr. Bruce Sinclair, then a doctoral candidate studying at Case Institute of Technology, had some time earlier selected the history of The Franklin Institute as the topic of his dissertation. With his consultation, we settled upon the Institute's early investigation of steam boiler explosions as a significant undertaking that exemplifies the historic involvement of our institution in the concerns and affairs of science, industry and the nation.

We were fortunate, too, that Mr. Sinclair could divert sufficient time from his broader study of the Institute to prepare this study-in-depth of the steam boiler investigation.

He has performed a very craftsmanlike piece of work, reconstructing the spirit and color of the times, the men and their task, while indicating the relevance of this episode to the present. His book fulfills, in every respect, our wish to commemorate properly the dedication of The Franklin Institute Research Laboratories.

Wynn Laurence LePage
President, The Franklin Institute

Philadelphia, August 1966

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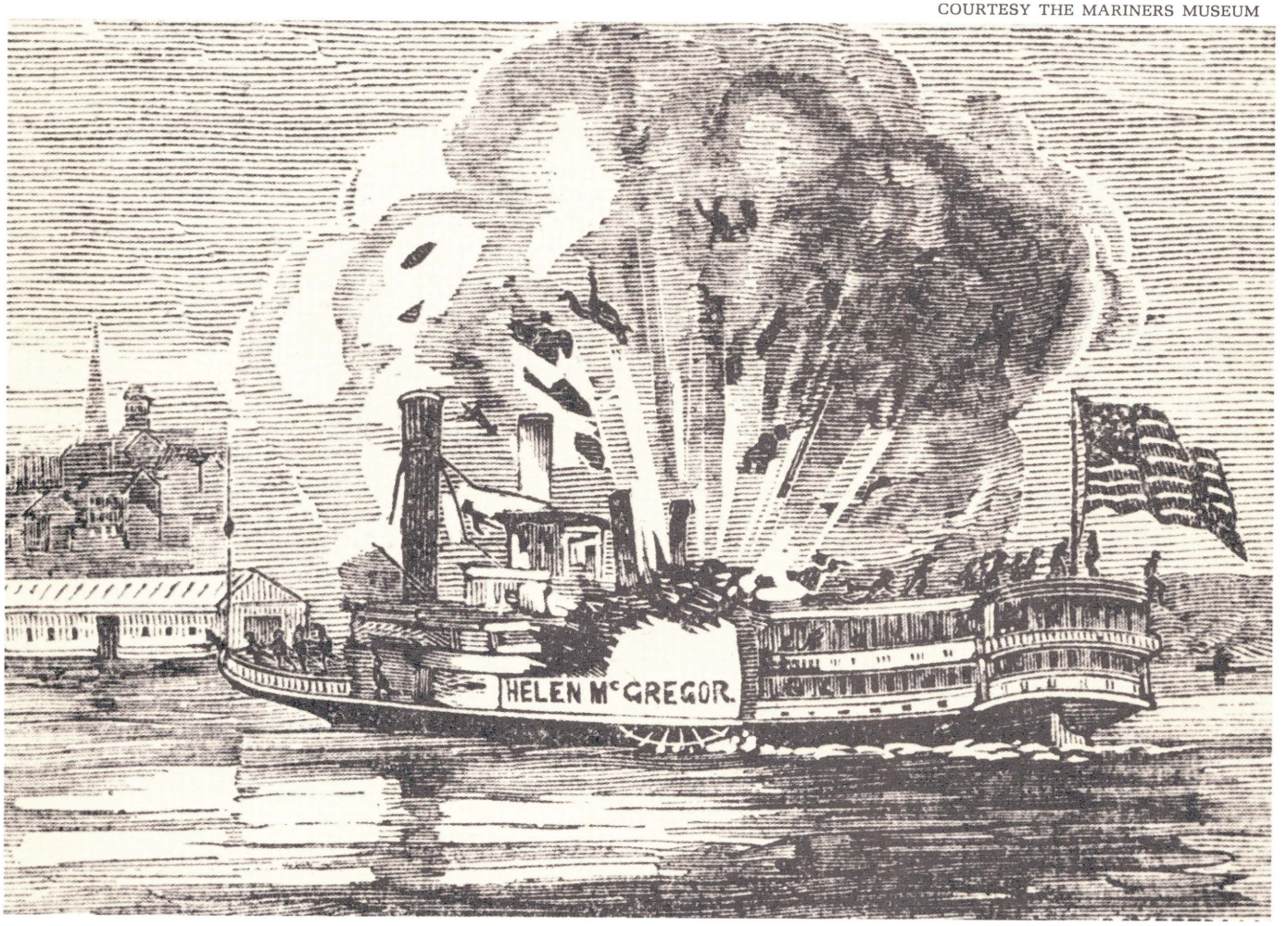

I. INTRODUCTION

On the morning of February 24, 1830, the steamboat *Helen McGregor* was torn apart by a violent boiler explosion while taking on passengers for her voyage to Louisville from New Orleans. Upwards of fifty people were killed and as many more injured. An eyewitness to the disaster later reported the scene and his efforts to aid those who were not killed outright. The first victim that he saw had been badly scalded by escaping steam. "He presented a most shocking and afflicting spectacle: his face was entirely black; his body without a particle of skin. He had been flayed alive." Soon the cabin was filled with the wounded and dying. "Some implored us, as an act of humanity, to complete the work of destruction, and free them from present suffering;" others lay silently as life ebbed slowly away. To add to the confusion, separated friends and families anxiously sought to learn each other's fate "for, in this scene of unmixed calamity, it was impossible to say who were saved, or who had perished."

The greatest loss of life had come among those who were standing on that part of the deck which was just over the boilers and the damage to that area of the ship was also described:[1]

> It was a complete wreck—a picture of destruction. It bore ample testimony of the tremendous force of that power which the ingenuity of man has brought to his aid. The steam had given everything a whitish hue,—the boilers were displaced,—the deck had fallen down,—the machinery was broken and disordered. Bricks, dirt, and rubbish were scattered about. Close by the bowsprit was a large rent, through which, I was told, the

[1] *Steamboat Disasters and Railroad Accidents in the United States* (Worcester: Warren Lazell, 1846), 127-131.

boiler, after exploding, had passed out, carrying one or two men in its mouth. Several dead bodies were lying around; their fate had been an enviable one, compared with that of others, —they could scarcely have been conscious of a pang ere they had ceased to be.

Early steamboat travel on the Mississippi was not necessarily the romantic picture which has so often been painted. The technology was still too new; a powerful force had been harnessed but its control was not always firmly in hand.

The *Helen McGregor* calamity dramatically focussed attention on the increasing hazard of steamboat navigation to public safety. By 1830, it was estimated that almost sixty boats had blown up, with a resultant loss of over three hundred lives. For over a decade, governments at all levels and in several countries had been wrestling with the problem. In America where there were more steamboats and more high pressure engines in use, the problem was especially acute. Growing commerce and a wide territorial expanse demanded fast, cheap transportation, and steamboats had come into extensive use. The west, in particular, depended on the steamboat for its very life. In a new country, however, with little tradition of governmental authority to control a public menace, few guidelines for the regulation of private industry, and without a national scientific or technical body, there seemed no agency suitable or capable of dealing with the problem, no way of obtaining the expertise necessary for sound legislation.

Impelled into this apparent vacuum by motives of public spirit and the urge for useful service, The Franklin Institute of the State of Pennsylvania began its own investigation into the causes of steam boiler explosions three months after the *Helen McGregor* disaster.

A committee led by Benjamin Franklin's brilliant great-grandson, Alexander Dallas Bache, was appointed to conduct the investigation. With funds provided by the U. S. Treasury Department, a series of original and creative experiments were performed during the course of the next six years. The investigation was the first outside research sponsored by the federal government and, in addition to Bache, it involved some of the nation's foremost scientific and technical talent. The research culminated in three reports, two of which gave a detailed analysis of the experiments and their results. The third report, Bache's *General Report on the Explosions of Steam Boilers*, was the centerpiece of the investigation. Here reprinted for the first time since its original publication in 1836, the report is a document of major importance in the history of American science and technology.

Bache's *General Report* was a masterful summary of the Institute's first significant scientific research and it provided Congress with the information it needed to regulate an evil which troubled the whole country. The experiments, in their scope and detail, were unparalleled in this country and scarcely equalled by any similar European research. Not only was the work of importance to government, it also profundly influenced the future development of The Franklin Institute. From the steam boiler investigation, the organization went on to a useful and creative career as the government's unofficial scientific advisor, at a time when it had no easy access to objective scientific and technical expertise. From essentially modest and local ambitions, the steam boiler research projected The Franklin Institute into national prominence. It was the beginning of a long tradition.

The original Franklin Institute (1825-1934),
South Seventh Street, Philadelphia

II. THE URGE FOR USEFUL SERVICE

By 1830, The Franklin Institute was beginning to attain a reputation for its research. The organization was not originally established for the purpose of conducting scientific and technical investigations, however, and how it developed that interest is an important part of the Institute's history.

When the Institute was founded in 1824, there was no clear plan for the conduct of scientific research nor, for that matter, any well-defined motivation toward that kind of activity. The organization was begun as a mechanics' institute with popular education as its primary goal. In 1824, the concept of education was already an essential part of the democratic dream, at the heart of the notion that birth did not set limits to a man's life, that his status was determined by his accomplishments rather than his lineage. In large part, the Institute was established to give form to the dream, and was no different in that respect from the other mechanics' institutes which flourished in the 1820's and 1830's. It was close in its aims to apprentices' libraries, evening schools, lyceums and similar organizations for self-improvement of the same era.

Two factors acted to differentiate the Institute from like-minded associations, however.

One was its location. Philadelphia in 1824, and for a decade or two still to come, was the scientific center of the nation. The University of Pennsylvania, the American Philosophical Society, the Academy of Natural Sciences and analogous organizations, as well as hospitals and a strong medical profession, all insured the city's pre-eminence in science. It was still, in spirit at least, the home of Franklin.

The other factor was talent. From the beginning the Institute enjoyed the active participation of the city's leading men of science, its foremost

manufacturers, and its most gifted technicians. It was only a matter of time before these men would lead the Institute into considerably more ambitious activities than those carried on by most other mechanics' institutes.

A Vehicle for Public Service

While education—the diffusion of knowledge—was the Institute's primary aim, there was also in the society's constitution the seed for scientific and technical investigations—a means for the advancement of knowledge. Section I of the constitution included among the institution's objectives the examination of new inventions. In its first quarterly report on April 15, 1824, the Board of Managers announced that special committees had been appointed for that purpose, and by the annual meeting in the following January eight new inventions had been submitted and examined. None was of great significance but a start had been made. In the summer of 1825, the process was regularized by the appointment of a Board of Examiners, two months later renamed the Committee on Inventions. The replacement of special committees by a single committee not only gave unity to the procedure of examining new inventions, it also gave the Institute a vehicle for the extension of its investigations when public service seemed to require it.

A special report on dry docks in 1826 shows how the new system worked. Designs for a dry dock had been submitted to the Committee on Inventions for its consideration. Preliminary investigation, however, revealed that American ship repair facilities were quite limited in the case of larger vessels and that their owners normally sent those ships to Europe when major repairs were necessary. The examination of a newly-invented dry dock was therefore expanded to a consideration of the larger issue of the nation's ship repair facilities, costs and methods of construction, the operation of such facilities, and their relationship to commerce and national defense. To carry out the investigation a special committee consisting mainly of shipwrights and naval officers, some of whom were not members of the Institute, was appointed. The formation of a Committee on Inventions had created a clearing house through which special investigations could be channeled. The Institute had solved the first problem in organizing itself for inquiries of a special nature. Routine analyses could be handled by the Committee on Inventions; cases which demanded unusual attention would be considered by special committees, made up of members from the Committee on Inventions and such other specialists as the situation required.

The whole report of the dry docks investigation, complete with illustrations, was published in 1827 in the *Franklin Journal*, which had been established under Institute sponsorship the previous year. It was a critical analysis of a major problem and the organization's managers took obvious pride in the accomplishment of their infant association. But what is perhaps more important is that the Institute's leaders developed a taste for activities above and beyond the ordinary examination of new inventions.

Water Power, the First Experiments

The next step necessary for an expansion of the Institute's research abilities was a project which originated in the Institute and was carried out by Institute members, with Institute-developed facilities. That opportunity came in the early spring of 1829, when Samuel V. Merrick, one of the founders of the Institute, proposed at a meeting of the Board of Managers on March 12th that the organization undertake a series of experiments to determine "the value of water as a moving power, and the relative effect produced by it upon the wheels of different constructions."

It was not, as it might seem, a backward step to conduct experiments on water power just as the stationary steam engine was coming into increased use in American industry. On the contrary, water power still provided the motive force for most of the country's manufacturers and was particularly important in the large milling centers of the mid-Atlantic and New England states. And equally important, there was need for a careful study of the matter. The most recent investigations of any standing were a half-century old and had been made in France and England. More often than not, American millwrights depended on tradition or cut-and-try methods rather than on accurately prepared tables yielding specific information in terms of wheel type, size, and head of water. It was to remedy this deficiency, and out of a growing sense of the organization's potential importance, that the managers of the Institute acted.

In its own internal shift from a local mechanics' institute to a scientific and technical association with national concerns, The Franklin Institute's water wheel experiments were of crucial importance. In the first place, it was an entirely self-contained project. One of the earliest resolutions

on the subject was that the committee to carry on the experiments should be made up only of Institute members. The water wheel, penstocks, and all related apparatus were constructed by the committee specifically for the purposes intended. Originally, it was thought to use city-owned facilities at the Fairmount Water Works, but upon consideration the committee determined that they could achieve more satisfactory results if they constructed their own building and machinery. It took most of the fall of 1829 to install the water wheel and prepare associated apparatus and the experiments were begun early in the winter of 1830. A research plan had already been devised and tabular forms printed, so that the actual work of experimentation progressed quickly. By March the inquiry was largely completed and part of the committee's report had already been prepared for publication in the *Journal of the Franklin Institute.*

A series of hydraulic experiments on the discharge of water through apertures of different size and under varying pressure was continued in the spring of 1830, but the original intent of the investigation had been satisfied. The Institute had initiated and carried out a significant set of experiments in the solution of an important question. And the conduct of the affair had been sufficiently impressive to gain the financial support of those best able to appreciate its merit. The water power inquiry also brought the Institute some fame outside the country. When the report was published, the editor of the London *Mechanics' Magazine* noted that the investigation was exactly the same kind which the newly-formed British Association for the Advancement of Science was expected to undertake. The Institute's water power research, he added, "constitutes another of its exclusive claims to the favor of the scientific public."[2]

The Institute Engages a New Problem

Spurred on by success, the Board of Managers, at the same time the water power experiments were being concluded, engaged a new problem. The Institute had now developed most of the elements necessary for the prosecution of scientific research. The zeal to carry out such activity was clearly manifest. With the water power inquiry, a series of experiments was planned and executed, utilizing test equipment designed for the purpose. A small but influential group of men within the organization had gained valuable experience in the conduct of research. Finally, in the best scientific fashion, the fruits of research were published, not only making the knowledge available, but changing the quality and character of the Institute's *Journal* in the process. With zeal, talents, and a voice, the Institute's managers self-consciously sought out a problem which had interest to the mechanic arts of the country but was also of major public concern. In that same spring of 1830, they determined to investigate the causes of steam boiler explosions. When the *Helen McGregor* blew up it was the most disastrous steamboat accident which had yet happened and the nature of the event demanded action.

Earlier Inquiries Unsuccessful

There had been previous investigations of the subject. In two cases, governmental inquiries had been instituted, although neither was particularly successful in producing regulatory legislation, primarily because of the difficulty of separating public and private interest.[3] The first government sponsored inquiry in this country occurred in Philadelphia. The select and common councils of the city appointed a joint committee in 1817 to consider what regulations might be imposed on the use of steam and to make appropriate recommendations to the state legislature. Expert testimony was obtained from some of the city's prominent scientists and engineers, and their advice was incorporated in a memorial to the legislature, but the state failed to take any action. When the high-pressure steamboat *Aetna* exploded in New York harbor in 1824, killing over a dozen people, the accident again pricked legislative consciences. A Congressional investigation was established but again no regulation came of the effort.

The Franklin Institute had itself been concerned with the problem prior to 1830. At its first annual exhibition of domestic manufactures in 1824, the Institute offered a prize to anyone who could devise a means of preventing steam boiler accidents. At a Board of Managers meeting on June 25th of the following year an inquiry was proposed "to investigate the probable causes of the accidents which happen to steam engines and consider the means which would be most effectual in preventing them." A committee composed of William H. Keating, Robert M. Patterson, and Samuel V. Merrick was appointed, but apparently no further action was taken. However, beginning in 1826,

[2] Quoted in *The National Gazette and Literary Messenger* (Philadelphia), July 7, 1832.

[3] The development of federal steam boiler regulations, with information on the Institute's role in that process, is ably treated in a recent article by John G. Burke, "Bursting Boilers and the Federal Power," *Technology and Culture*, VII (Winter, 1966), 1-23.

when the *Franklin Journal* was established, a continual stream of articles on the subject reflected the interest of the Institute and of the *Journal's* editor, Thomas P. Jones. In his second volume, for example, Jones asked the eminent, if occasionally eccentric, University of Pennsylvania chemistry professor, Robert Hare, to comment on the causes of boiler explosions. One of Hare's remarks sums up what must have been a widely held attitude:[4]

> Steam-boats will be blown up, sail-boats will be upset, and stages will [be] run away with, broken down, or overturned in despite of any preventative.

A Scientific Basis for Action

In the face of legislative inaction and uncertainty as to the proper role either for government or private industry, conflicting opinions over the true causes of steamboat explosions only exaggerated the problem. The first and most important step was to join theory and fact, to discover how and under what conditions boilers exploded. Responsibility could then be more clearly designated, and legislation which would most likely solve the problem could be enacted.

Nowhere is the problem and its potential answer more clearly stated than in the report of the committee appointed on May 13, 1830 by the Institute's Board of Managers to consider the expediency of such an investigation. The committee presented its conclusions to the Board on June 10th. In recommending that the Institute undertake an investigation, the report initially struck a tone similar to that of Dr. Hare: "The application of steam to navigation has been attended with such unforseen advantages to the world at large and to our country in particular that no series of accidents in Steam Boats, however frequent in their recurrence, or fatal in their consequences, could probably deter the public from the use of them." However, the committee went on to say that if steamboats continued to operate unchecked by any regulation, there must be an even greater loss of life and waste of property.

The issue was clear. Accidents were avoidable; somewhere in the community there was authority to protect the general public against a serious evil; and regulation depended upon a knowledge of the real causes of explosions. The committee's report also revealed an acute recognition of the difficulties confronting legislative action:

> Could the question meet with that thorough discussion & investigation before a committee of Congress which its importance & difficulty requires we should forbear recommending to the institute to take any steps in it; but it is well known that from the many subjects which press upon the attention of Congress, & from the indisposition to follow the British precedent of instituting enquires founded upon the evidences of practical and expert men, it becomes a difficult task for a committee of their body to possess themselves of a knowledge of the facts that have been developed during an experience of twenty years over a country so extensive as ours.

With a clear understanding of the problem, a recognition of the means for its solution, and a corresponding knowledge that normally-constituted authority was limited in its ability to deal with the issue, the committee's conclusion was inescapable. In their judgment, a "public body whose views are so well known & appreciated by the community as to place their motives beyond suspicion," could best carry out the necessary investigation. "That our Society constitutes such a body," they stated, "no one will doubt." The report was accepted and the Board resolved to appoint a committee of seventeen members "to examine into the causes of the explosions of the Boilers used on Board Steam Boats and to devise the most effectual means of preventing the accidents or to diminish the extent of their injurious influence." William H. Keating, Robert Hare, Samuel V. Merrick, Alexander Dallas Bache, Isaiah Lukens, James J. Rush, James Ronaldson, Robert M. Patterson, Frederick Graff, James K. Mitchell, George Fox, Benjamin Reeves, Thomas P. Jones, Walter R. Johnson, James P. Espy, Matthias W. Baldwin, and George Merrick made up the committee.

Lack of Funds Curtail the New Study

If there was no question of the need for an investigation, the method of prosecuting the inquiry was at least somewhat in doubt. A fairly extensive series of experiments on the nature and properties of steam had apparently once been considered, perhaps as an adjunct to the water power experiments. However, the water power investigation, in the opinion of the Board of Managers, had temporarily exhausted the liberality of the Institute's friends and they had postponed any experimental inquiry into steam power. The investigation which the committee proposed on June 10, 1830 was not, therefore, to be based on experi-

[4] *The Franklin Journal and American Mechanics' Magazine*, II (September, 1826), 148.

ment. The Institute, through the medium of a Committee on Steam Boilers, was to act instead as a fact-finding agency, collecting data on boiler explosions, sifting the evidence, and—using the experience of scientific and practical men—determine, to their best judgment, the causes and prevention of explosions. To that end, the committee drafted a circular which it sent to all those who might be acquainted with the subject.

Coincidentally, the *Helen McGregor* disaster triggered a request for another federal investigation at almost the same time that the Institute determined on its own inquiry. The House of Representatives passed a resolution on May 4, 1830, directing the Secretary of the Treasury, Samuel D. Ingham, to report on the problem of steamboat boiler explosions, and appropriated a sum of money for his investigation. Ingham took the same course as that initially pursued by the Institute. He prepared a circular designed to elicit as accurately as possible the circumstances surrounding boiler explosions, with the hope that the information would reveal a pattern which might lend itself to correction. The circulars were distributed among customs collectors, steam engine manufacturers, and others familiar with steamboat operation. Ingham also hired two special investigators—one on the Atlantic, perhaps Professor James Renwick of Columbia University, and one on the Ohio River, Thomas W. Bakewell of Cincinnati.[5] These men were to conduct interviews, supplementing by personal contact the information obtained from the circulars. Response to the Secretary's efforts was poor, however, and he was later forced to admit that "although some valuable information has been collected, there is yet no satisfactory explanation of the causes of the explosion of steam boilers."[6]

Federal Support Is Offered

In the summer of 1830, however, Ingham learned of the parallel investigation launched by the Institute. A Pennsylvanian from Bucks County, Ingham was undoubtedly familiar with the Institute's reputation, and in mid-August he wrote suggesting cooperative action, noting that the funds at his disposal "might be usefully applied in making some experiments." The Secretary's letter very quickly altered the nature of the Institute's investigation. At the next meeting of the Committee on Steam Boilers, a sub-committee composed of Keating, Bache, S. V. Merrick, Baldwin, Espy, and Reeves was appointed to draft a plan of experiments to be submitted for the Secretary's consideration, and in a letter to Ingham on August 31st the Institute's services were offered "in the prosecution of any experimental inquiries that may be deemed judicious." Ingham responded by asking for information on the proposed experiments and an estimate of their costs. Bache submitted a set of experiments estimated to cost $1500, which was adopted with some minor amendments and forwarded to the Secretary. Acting on the assumption that their proposals would be accepted, the committee also entered into negotiations with David H. Mason, a tool-maker and engraver of some local reputation, to superintend the experiments. All that was wanting was the Secretary's approval, and on the 21st of October, 1830, Ingham wrote expressing his support and promising the necessary financial assistance. With backing from the Secretary of the Treasury and supported by federal funds, The Franklin Institute's investigation into the causes of steam boiler explosions was now well launched.

The Research Program is Launched

To carry out the proposed experiments two initial steps were required. It was necessary to assign responsibility for the execution of the research and it was necessary to design and construct suitable experimental apparatus.

The first problem was solved quickly and naturally; the sub-committee which had drafted the course of experiments was made responsible for the conduct of them.

The experimental apparatus came with a little more difficulty. A plan with drawings was prepared and submitted to the general committee. Final arrangements were made with David Mason to execute the experiments, and through the courtesy of Samuel V. Merrick the committee acquired the use of a vacant lot upon which they could construct an experimental building. Considerable discussion also preceded the actual development of the testing machinery. A glass boiler was proposed for certain of the experiments in which it was important to observe water action within the boiler. An iron boiler enclosed either in a wire cage or within

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[5] Renwick edited several American editions of Lardner's *Treatise on Steam Engines* and corresponded with Ingham on steam boilers, safety apparatus, and related subjects at the time the Secretary began his investigation. Extracts of that correspondence are printed in *Communications Received by the Committee of the Franklin Institute, on the Explosions of Steam Boilers* (Philadelphia, 1832). For details on Bakewell, see Bruce Sinclair, "Thomas Woodhouse Bakewell's Autobiographical Sketch and its Relation to Early Steamboat Engineering on the Ohio," *The Filson Club History Quarterly*, XL, 235-248 (July, 1966).

[6] *Letter from the Secretary of the Treasury, Transmitting a report on the subject of steam boilers*, March 3, 1831 (House of Representatives Document No. 131, 21st Congress, 2nd session), 1.

another larger boiler was suggested for use in those experiments where an explosion was likely to result. Merrick was chairman of a sub-committee assigned to prepare the apparatus, and by early November most of the details had been worked out for the construction of the boiler to be used in the first set of experiments. It was to be a glass cylinder fourteen inches long and eight inches in diameter, with brass heads at each end secured by a rod running from head to head through the cylinder. Thermometers were attached to measure both steam and water temperatures. A glass gage was also used to indicate water level and allow the experimenters to check the efficacy of the gage against the observed water level in the boiler. Finally, a half-inch common safety valve was attached to the boiler. Determination of the remainder of the apparatus was temporarily postponed, although on January 4, 1831, Merrick reported that all the test gear was nearly ready for use. In its experimental building the committee settled on a horizontal iron boiler, fixed in a brick-work furnace, with an attached water pump, safety valve, and thermometers. A glass viewing plate at the end of the boiler allowed for direct visual observation. Instead of enclosing the whole in a wire cage or another boiler, the most dangerous experiments were conducted in an abandoned quarry.

Bache's series of experiments was quite straightforward in nature. The committee meant to test by direct experiment the most widely held ideas of the causes for boiler explosions. Even when these notions were contrary to accepted theoretical facts, the committee still felt the necessity for laying old bones to rest. As early as 1817, for instance, as a result of a British Parliamentary investigation, scientific men knew that a gradual increase in pressure could sunder a boiler just as effectively as the sudden production of steam if the force generated was not worked off. Yet on the western waters of the United States many steamboat operators held firmly the opinion that a sufficient water supply was the best guarantee possible against a boiler explosion. It was only when water was low, they reasoned, that an excess of highly heated steam burst the boilers. Therefore, the committee included in its experiments two which were designed to offer conclusive proof that the notion was in error.

In a deserted quarry on the banks of the Pennypack River boilers of iron and of copper were purposely exploded to prove the point. In the case of the iron boiler the demonstration was particularly effective since leaks in the boiler acted somewhat as a safety valve, yet the pressure gradually increased to the point that the boiler exploded, throwing parts in all directions. The result with a tight copper boiler was the same, except that the explosion was even more violent.

The majority of the experiments, however, were conducted at the Institute's test installation in the city. While many of the experiments had a distinctly practical aim—to disprove false notions and to lay the basis for appropriate legislation—the Institute's steam boiler investigation had a theoretical side, too, with significant connotations not only for the Institute, but for the state of American science in general.

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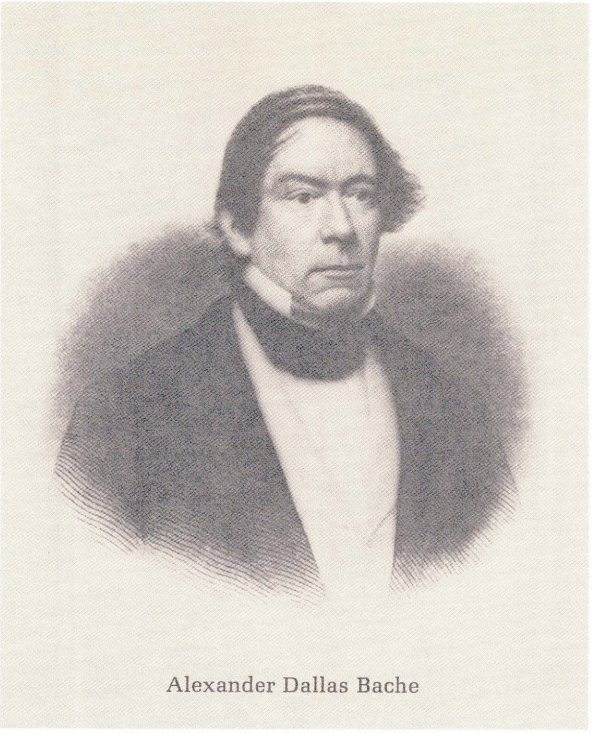

Alexander Dallas Bache

III. GIFTED, ENERGETIC MEN

Although the original committee assigned to the investigation consisted of seventeen members, the bulk of the work and the major share of interest was borne by a small handful of gifted, energetic men. In varying combinations they were linked socially as well as intellectually, by business interests as well as by avocation. Of the whole committee seven men—William H. Keating, Alexander Dallas Bache, James P. Espy, Walter R. Johnson, Matthias W. Baldwin, Samuel Vaughan Merrick, and Benjamin Reeves—were clearly the ones most responsible for planning the investigation and carrying it out. The first four were men of science; the last three were industrialists. It was a near perfect blend of science and practicality, the combination which the Institute sought most to embody. But even the industrialists were more than simply men of affairs, especially Baldwin and Merrick.

After an apprenticeship in a Philadelphia manufacturing jewelry firm Matthias Baldwin established his own business at the age of twenty-four.[7] The concern failed to give scope enough to Baldwin's ambitions or talent, however, and about 1825, when he was thirty, Baldwin formed a partnership with David Mason to manufacture engraver's and bookmaker's tools. From that point the business branched out to include binder's presses and calendaring and calico printing rolls. In 1827 Baldwin built his first locomotive, and from then on his manufacturing career was settled. By the time of his death, Baldwin's firm had built over 1500 engines and as the nation's foremost locomotive producer Baldwin had also gained a reputation for inventiveness and mechanical ingenuity.

It was more than his interest in steam power which drew Baldwin into the Institute's boiler investigation. He had been one of the organization's original members and served on the Board of Managers for thirty-six years following his election in 1827. Baldwin had been an active participant in the water power inquiry and was also the organization's vice-president for a number of years. He was as well a member of the American Philosophical Society, the American Horticultural Society, the Pennsylvania Academy of Fine Arts, and Philadelphia's Music Fund Society. Baldwin also became well known for his philanthropy. He was

[7] For more details of Baldwin's life, see the *Memorial of Matthias W. Baldwin* which was privately printed in Philadelphia in 1867, and Thomas Coulson's article, "Some Prominent Members of the Franklin Institute: 3. Matthias William Baldwin, 1795-1866" *Journal of The Franklin Institute*, CCLXII (September, 1956), 171-184.

an early and strong champion of Negro rights and supported a variety of religious and educational efforts. Baldwin was a quiet, unostentatious man and the force of his personality does not stand out strongly in the steam boiler committee's records. But his steady attendance at meetings reflects the nature of his interest and personality. It was the dimension of Baldwin's mind as well as his practical talents which gave the Institute's investigation the standing it attained.

Samuel Vaughan Merrick

Unlike Baldwin, Samuel Vaughan Merrick was born into a world of position and affluence, and his status in the inquiry shows the difference.[8] His father, an English Unitarian clergyman, retired early in life to Hallowell, Maine, prosperous enough to cultivate his interests in literature, music and science. But on his mother's side of the family, Merrick's backing was even more impressive. His grandfather was Samuel Vaughan, a wealthy London merchant with large scale colonial interests. His uncle, Benjamin Vaughan, studied under Joseph Priestley at Warrenton Academy, was Franklin's close friend and edited an edition of his writings, wrote extensively on political economy, and played a major role in the peace negotiations of the Revolutionary War. Benjamin ultimately settled in Maine also, where he carried on an active scientific and literary life and conducted a number of agricultural experiments. His library was reputedly the second largest in New England. Through Petty Vaughan, who acted as London agent for the Institute, the American Philosophical Society, and many traveling American scientists, family connections gave Merrick a link with a significant segment of London's intellectual life. Another maternal uncle, John Vaughan, was a wealthy Philadelphia wine merchant who also moved in select cultural and intellectual circles. Vaughan was an active officer of the American Philosophical Society and the center of a scientific coterie which included many of the boiler explosion investigators as well as Joseph Henry and others of the same caliber. Thus by family connections, upbringing, natural talents, and ultimately business interest, Merrick was well prepared for a scientific investigation such as the Institute's boiler explosion inquiry.

[8] Additional information on Merrick can be found in Thomas Coulson's, "Some Prominent Members of the Franklin Institute: 1. Samuel Vaughan Merrick, 1801-1870," *Journal of The Franklin Institute,* CCLVIII (November, 1954), 335-346. Details on members of the Vaughan family are most easily located in the *Dictionary of American Biography.*

Furthermore, Merrick had considerable interest in the Institute itself. More than any other single person he was responsible for the founding of the organization, and for a period of thirteen years served as its second president. At one time or another Merrick sat on most of the important committees within the Institute. He was instrumental in initiating the water power investigation, active in the Institute's later meteorological studies, and one of the commanding figures in the boiler explosion inquiry. To his interest in science and engineering Merrick added considerable organizational talent. He built a near-bankrupt fire engine manufacturing firm into one of the nation's largest machine shops, the Southwark Foundry; was president of the Pennsylvania Railroad; and had interests as well in a variety of related enterprises.

William H. Keating

William H. Keating (1799-1840), who with Merrick planned the preliminary meetings which established the Institute, came to his interest in the organization along a slightly different path from that of Merrick.[9] The latter was forced to learn something about mechanics and engineering when he became a partner in the fire engine factory. Keating, on the other hand, had received as thorough a training in science and engineering as the educational systems of America and Europe could provide. He graduated from the University of Pennsylvania in 1816 and then spent the following three years studying geology, mineralogy, chemistry, and mining engineering in the technical schools of Great Britain and Europe. When he returned to his native city he was not only one of the best trained scientists in the country, his education had also a distinctly practical bent. He was convinced of the necessity for applied science training; and once home, his earliest efforts were directed towards the establishment of that kind of an educational system in Philadelphia. He was familiar with the newly-formed mechanics' institute in New York and apparently saw in that type of organization the vehicle for his ideas. Keating was reputedly one of the first to employ laboratory instruction in his chemistry course at the University of Pennsylvania. His later efforts on behalf of a collegiate school of arts and sciences to be attached to the Institute also reflect his continued

[9] In addition to notice in the *Dictionary of American Biography,* an article by Wyndham D. Miles entitled "A Versatile Explorer: A Sketch of William H. Keating," *Minnesota History,* XXXVI (1959), 294-299, gives the pertinent details of Keating's life.

concern with applied science education.

Like so many of his colleagues on the committee, Keating was a man of broad interests and considerable talent. In addition to his efforts in the founding and management of the Institute, Keating taught chemistry and mineralogy at the University of Pennsylvania, and wrote fairly extensively on those subjects. He was also a practicing mining engineer and one of the founders of the Philadelphia and Reading Railroad. His intellectual interests are illustrated by an active membership in the American Philosophical Society, the Academy of Natural Sciences, and the Philadelphia Society for the Promotion of Agriculture. He was concerned in the affairs of a local hospital and was involved as well in the problem of prison reform. Keating also sought means of implementing his interests and beliefs. He entered politics and served a two-year term in the state legislature. He then studied law and was admitted to the Pennsylvania bar in 1834.

It was Keating who proposed the Institute's investigation into the causes of steam boiler explosions. He was not unfamiliar with the subject; he had been one of the members of the Institute's 1825 attempt to investigate boiler accidents. Keating had also earlier served on Major Stephen H. Long's exploring expedition to the headwaters of the Mississippi River, where a series of mechanical incidents acquainted him with the often tenuous margin of surety in western steamboat operation. With Keating's scientific training, experience and interests, it was perhaps only logical that he was appointed chairman of the committee which was assigned the investigation. He held that position for a year and a half, but the pressure of his other affairs compelled him to resign, and Alexander Dallas Bache was subsequently elected to lead the committee's inquiry.

Walter R. Johnson

Governmental support of scientific and technical investigations was an issue which figured strongly in the lives of both Walter R. Johnson and James P. Espy. Both also came to the steam boiler investigation from secondary school teaching careers. Johnson graduated from Harvard in 1819 and taught school in Framingham and Salem, Massachusetts.[10] In 1821 he was appointed principal of Germantown Academy in Pennsylvania, where he remained until 1826 when he was selected to head the high school which the Institute established in that year. Johnson's tenure as principal of the high school was apparently quite successful in terms of the number of pupils enrolled and the quality of education imparted. He was unable to agree with the Board of Managers on the financial terms under which he would conduct the school, however, and Institute sponsorship ended three years later in 1829. Johnson continued the school for an additional three years at the Institute under a rental agreement, and then moved to different quarters for another three or four years.

While Johnson developed some reputation in educational circles for his extensive writing on the subject and for the pedagogical reforms developed at the Institute high school, his standing in the steam boiler investigation depended on his scientific knowledge. He had been appointed to the professorship of Mechanics and Natural Philosophy in the Institute in 1829, and from 1831 to 1837 served as Professor of Natural Philosophy. During that time, Johnson's interests turned increasingly from educational affairs to science. He became closely connected with the Academy of Natural Sciences and wrote articles for their *Proceedings* as well as for the *American Journal of Science* and the Institute's *Journal*. He was one of the founders of the Association of American Geologists which was organized at the Institute in 1840. When that society later became the American Association for the Advancement of Science, Johnson served as its first secretary. The steam boiler investigation, however, gave Johnson's scientific career its real direction and thrust.

Sub-Committee on Strength of Materials

Included in the series of experiments proposed by the Institute was one to "ascertain the relative strength of iron and copper at different temperatures and of different thicknesses." It was an experiment of an essentially different nature from the others, and had to do with the material of the boiler itself rather than with any of the conditions which might be created within the boiler. Implementation of the experiment therefore required different methods and apparatus from those required for the remainder of the inquiry. Johnson appears to have been attracted to that phase of the research early in the investigation. In November, 1830, for example, he first raised the question of experiments on the strength of materials and by January a sub-committee for that purpose was appointed, with Johnson as chairman. From that point

[10] The best single source for information about Johnson is George E. Pettingill's article "Walter Rogers Johnson," *Journal of The Franklin Institute*, CCL (August, 1950), 93-113.

on, the strength of materials experiments became a separate and distinct inquiry.

Bache and Benjamin Reeves were the other members of the sub-committee but the records which do remain suggest that Johnson played the major role. Bache was abroad when the sub-committee's report was finally made, and at least did not participate in its writing. Reeves is an indistinct figure. He attended meetings faithfully but the lack of historical information about any other of his activities suggests that he did not play a significant role in the project. Johnson's personality did not lend itself to group research; he was a lone investigator and always considered the strength of materials study his own personal work. It was over a year after the sub-committee was appointed before experiments were actually begun. A machine to test the strength of materials was constructed, probably one of the earliest ever used in this country, along with several other fairly sophisticated instruments to give measurements of the effect of temperature on tensile strength. The experiments were minutely detailed and involved considerable effort. Johnson was a patient and careful experimenter. His work was not marked by theoretical insight nor did it lend itself to synthesis; it was a laborious compilation of details, doggedly pursued over a period of five years. Some of Johnson's conclusions were important and bore directly on the problem of boiler explosions, but the form and style of his report was quite different from those of the others which issued from the investigation. There was no impetus for reform in Johnson's report, nor was it framed to elicit legislative action.

Johnson's Later Career

It was the nature of the inquiry which dictated the form of the report, however, not an antipathy in Johnson's mind to a connection between government and science. The Institute's experiments, after all, had only come about as a result of federal funds, and Johnson spent much of the rest of his life seeking governmental support for scientific research. In 1836 he was selected to take charge of the geophysical research for the United States Exploring Expedition, a scientific survey commanded by Lt. Charles Wilkes of the Navy. Jeremiah Reynolds, principal promoter of the expedition, wrote of Johnson to President Andrew Jackson:[11]

> Prof. Walter R. Johnson of Philadelphia, of whose attainments it is unnecessary to speak, has I believe signified his willingness to take charge of Meteorology, Magnetism, etc. He would prove a valuable acquisition to the scientific corps, being unquestionably qualified to conduct the researches in this department to the satisfaction of the government and the public.

Johnson never sailed with the expedition, however. A factional dispute over the role to be played by civilian scientists and naval officers soon developed, and further internal problems delayed departure for two years. When the conduct of physical science research was finally given to naval officers, several of the civilian scientists, including Johnson, were left behind.

Johnson continued his efforts to link his work with governmental support. In 1838, for example, the year the Wilkes Expedition sailed, he printed a memorial to Congress calling for the establishment of a National Institution which would finance experimental work in the physical sciences. His most significant research after the strength of materials report was a lengthy investigation into the nature and properties of coal, originally proposed to the Secretary of the Navy and authorized by Congress in 1841. Johnson also conducted several more investigations for the Navy Department in the years immediately following. In 1842 he reported on tests of sheathing copper used on Navy ships, and in the next year was one of the commissioners appointed to report on floating dry docks. Along with Thomas P. Jones, editor of the *Journal of The Franklin Institute*, Johnson carried out in 1844 a series of experimental trials for the Navy of inventions designed to prevent the explosion of steam boilers. He never succeeded in persuading governmental authorities to appropriate funds for the further researches on the properties of iron, copper, and coal which he hoped to conduct. But at a time when institutional and governmental support of science was limited, Johnson fashioned a useful scientific career, based on his investigation for The Franklin Institute into the strength of materials.

James P. Espy

Although they were quite different in personality, Johnson and James P. Espy shared similar careers. Both were educators before they were scientists; both became closely connected with governmental support of science; and in both cases, their scientific careers stemmed from their con-

[11] Nathan Reingold, *Science in Nineteenth-Century America: A Documentary History* (New York: Hill and Wang, 1964), 116-117.

nection with The Franklin Institute. Espy was born in Pennsylvania but grew up in Kentucky and Ohio.[12] He was educated at Transylvania University in Lexington, Kentucky, and then followed a slightly peripatetic career similar again to Johnson's. He taught school and studied law; was principal of an academy in Cumberland, Maryland, for five years; and by the mid-1820's had established himself in Philadelphia as a teacher of mathematics and the classics.

Espy's initial connection with The Franklin Institute began in the summer of 1824 when he was elected to membership. Two years later he was selected to conduct the organization's evening mathematics school, although the appointment lasted only until 1827. The school, either under previous or succeeding teachers, never met with the hoped-for response, and it was finally closed in 1831. Espy's connection with the school, and his own expanding scientific interests, however, drew him increasingly into the circle of those members of the Institute who actively carried on research in scientific and technical subjects.

When the Institute's investigation into the motive force of water was begun in 1829, Espy was appointed to the committee which was to conduct the experiments. He soon came to play a leading role in the inquiry. He was a member of the sub-committee responsible for preparing a plan for the experiments and was actively involved in their prosecution. Upon completion of the water wheel experiments, Espy, Bache and John Agnew, Samuel Merrick's partner in the fire engine manufactory, were assigned the additional hydraulic experiments which the committee next took up. Espy also published several articles in the *Journal* on both series of experiments. By the time the steam boiler investigation was instituted, his appointment to that committee was a logical choice.

Espy's role in the steam boiler investigation was important, but not commanding. He was a member of the sub-committee which planned and executed the experiments; however, his influence was not so clearly discernible as it had been in the water power research. By the early 1830's Espy's interests were increasingly devoted to meteorology, the science in which he was to gain his reputation, and he devoted correspondingly less of his attention to other matters.

A Common Interest in Meteorology

Interest in meteorology was common to several of the men who participated in the steam boiler investigation. Espy's concern with the subject dates at least from 1825 when he read a paper "Concerning the causes of fluctuation of the barometer," before a meeting of the American Philosophical Society. Both the Philosophical Society and the Institute soon established committees to make meteorological observations. The American Philosophical Society had such a committee in operation as early as 1829. The Institute's committee, consisting of Reuben Haines, Bache, Keating, Johnson and Espy, was appointed in January, 1831 at Bache's suggestion. In November of the same year the Institute appropriated funds to purchase equipment for its committee and an increasing number of articles on the subject began to appear in the Institute's *Journal*.

Since many of the same men were involved in the meteorological observations of both the Institute and the American Philosophical Society, it was only a matter of logic to join forces and in 1834 a joint committee of seven members was formed, four of whom—Bache, Espy, Henry D. Rogers, and Sears C. Walker—were active in both organizations. Espy was chairman of the joint committee. Descriptive circulars and standardized forms were printed and given wide distribution in an effort to secure volunteer observations from widely scattered localities. Collected and analyzed, these observations were to be the basis for Espy's theory of storms. When the joint committee was formed, Espy strongly urged that Congress be petitioned to support the project. No governmental aid was secured until 1837, however, when the state legislature appropriated funds to supply the volunteer observers with apparatus and for Espy's salary as meteorologist.

Espy's meteorological efforts as chairman of the joint committee brought him considerable fame. In 1836 he was awarded the American Philosophical Society's Magellanic Prize for his storm theory, which he was later invited to explain before the British Association for the Advancement of Science and the French Academy of Sciences. He published his major work *Philosophy of Storms* in 1841 and was appointed meteorologist to the War Department in the following year. Espy was wrong, in fact, in his theory of the shape of storms, but correct

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[12] The best short account of Espy's scientific career is Bache's eulogy before the Regents of the Smithsonian Institution, printed in the *Annual Report of the Board of Regents of the Smithsonian Institution . . . for the year 1859* (Washington: Thomas H. Ford, 1860) 108-111. Other details of his life are given in the *Dictionary of American Biography*.

about the effect of heat in the creation of moisture. That understanding, and his efforts to promote the systematic collection of data through large networks of observers, were his two significant contributions to meteorology.[13] Espy remained in Washington for the rest of his scientific career, working variously with different agencies as meteorologist, but never really finding the support he sought for a grand array of observers throughout the country.

While Espy's meteorological research carried him away from the Institute, the investigations he conducted there were never very far in spirit from the steam boiler inquiry. He and his colleagues were a remarkable band of men; and while their interests ranged widely, they were linked in their efforts by a close network of relationships.

"Kindred Spirits"

From the beginning, the Franklin Institute's experiments into the causes of steam boiler explosions were part of a larger scientific effort. The men who conducted them were crusaders, dedicated to research and concerned for the standing of American science. Only a metropolis such as Philadelphia could have provided the support and outlets for such a group of men. Their close association, in turn, made the city the scientific center which it was. They created, in a sense, a Philadelphia brand of science, which was stamped on the steam boiler experiments just as it was on the other research of the group. "Kindred spirits," Bache called them, "ready to discuss the principles or the applications of science, and prepared to extend their views over the whole horizon of physical and mechanical research.[14]

They met together at meetings of the Institute and the American Philosophical Society. They worked together on a wide variety of experimental researches and on occasion made common defense against a scientific rival. For example, Espy called Johnson's attention to an article in the *Revue Encyclopédique* on hydraulics. He and Johnson repeated the experiments at one of the Institute's monthly conversation meetings and Johnson published the results in the *American Journal of Science*. When Bache became involved in a controversy with Professor Denison Olmstead of Yale over the analysis of a meteoric shower, Espy joined the fray in an article for the Institute's *Journal*, basing his evidence on the reports from his corps of weather observers. In a similar fashion, Bache and other members of the Philadelphia coterie sided with Espy in his long dispute with William C. Redfield over a true scientific theory for the action of storms.

Not only did these men work together, they sought also to diffuse the knowledge which they gained. Primarily through the efforts of Merrick and Bache, but with aid from their colleagues, they transformed the *Journal of The Franklin Institute* from a mechanics' magazine into a genuine scientific publication. Both Johnson and Bache also published articles which stemmed from the boiler explosion research in the *American Journal of Science and the Arts*, the major American scientific periodical at that time. With Benjamin Silliman, its editor, the Institute's publication committee freely exchanged articles and the wood cuts for supporting illustrations.

In addition to all the professional associations which drew them together, these same men were linked socially. Wistar parties—convivial evenings for men of science and learning—were a Philadelphia institution.[15] Bache, Joseph Henry, Espy, Henry D. Rogers and Sears C. Walker were also joined together in a small private club based on their mutual interest in the physical sciences. It was formed, Bache once noted, "for promoting research, and especially for scrutinizing the labor of its members."[16] The club flourished until about 1837, when both Henry and Bache went abroad.

Bache actively tried to draw Henry down from Princeton into the Philadelphia circle, urging the publication of his articles in the Institute's *Journal* and his attendance at meetings. For his part, Henry was attracted and whenever he planned trips to Philadelphia, additional meetings of the club were scheduled. In a letter to Bache he once compared his feelings about New York and Philadelphia:[17]

I almost always return from New York dis-

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13 As Nathan Reingold has pointed out in his book *Science in Nineteenth-Century America*, p. 92, meteorology was a field "in transition from folklore to science," and ripe for fact-gathering and theoretical speculation. For information on Espy's use of volunteer observers see Bruce Sinclair, "Gustavus A. Hyde, Professor Espy's volunteers, and the development of systematic weather observation," *Bulletin of the American Meteorological Society*, XLVI (December, 1965), 779-784.

14 *Annual Report of the Board of Regents of the Smithsonian Institution . . . for the Year 1859*, 109.

15 See Horace Mather Lippincott, *Early Philadelphia: Its People, Life and Progress* (Philadelphia: J. B. Lippincott Company, 1917), 295-299, for an account of the Wistar parties.

16 *Annual Report of the Board of Regents of the Smithsonian Institution . . . for the Year 1859*, 109.

17 Joseph Henry to A. D. Bache, Princeton, Oct. 25, 1839. Joseph Henry, Private Correspondence, Smithsonian Archives, Washington, D.C.

pirited in the way of science. I am there thrown among, as it appears to me, all the Quacks and Jimcrackers of the land. I am disgusted with their pretensions and annoyed with their communications. How different is my feeling on a return from the [city] of Brotherly love!! There is there jealousy and rivalry but also science and intelligence and [trade?] and money not the only things which occupy the mind.

Philadelphia was the scientific capital of America when the Institute's steam boiler investigation was begun, and not the least of the reasons for the city's pre-eminence was the small band of enthusiasts who were responsible for the most creative labors of her scientific and technical institutions.

One of the most remarkable features of the Institute's boiler explosion research was the comparative youth of the men who carried it out. At forty-five, Espy was the grand old man of the group when the inquiry was begun. Keating, who had proposed the investigation, was thirty-one. Baldwin and Johnson were a year apart in age; Baldwin was thirty-five, Johnson thirty-six. Merrick, at twenty-nine years, was the second youngest. Alexander Dallas Bache, who took over leadership of the research when Keating resigned as chairman and who was clearly the dominant figure in the investigation, had just celebrated his twenty-fourth birthday as the project was getting underway. He was already marked for an outstanding career. Great-grandson of Benjamin Franklin, Bache profoundly influenced the development of the organization which had been named in honor of his ancestor. His connection with the Institute, in turn, provided Bache with important experience in his future efforts to mold the course of American science and technology.

Alexander Dallas Bache

Bache was born in Philadelphia on July 19, 1806.[18] The force of his intellect was already evident by the time he completed his early education in local schools and he was admitted to the United States Military Academy when he was fifteen. West Point at that time had probably the best facilities in the country for a scientific education, and Bache graduated with highest honors. He was appointed to the faculty at the Academy following graduation, and then served two years as a Lieutenant in the Topographical Engineers, the Army's elite scientific corps. In the fall of 1828, however, Bache resigned his commission, accepted the professorship of Natural Philosophy and Chemistry at the University of Pennsylvania, and returned to Philadelphia to pursue a distinguished career.

It was not long before Bache's influence was felt at the Institute. He was elected a member in May, 1829. In the spring of the following year he was added to the Committee on Inventions and to the committee conducting experiments on water wheels. That summer, two months after the boiler explosion investigation was inaugurated, Bache was elected to fill a vacancy in the Board of Managers, a position he held, excepting his two years abroad from 1837-1839, until 1844. He was also a member of the Publications Committee and the Committee on Instruction, both centers of power within the Institute.

These assignments involved far more than performing the normal obligations a conscientious member owed his organization. Bache was concerned with the form and standards of science, and along with a small number of like-minded colleagues he worked to change the Institute from an instrument solely of popular education to a first-rate scientific and technical body.

His influence in shaping the Institute's character is discernible in many ways. His name seems always to appear on those sub-committees whose negative resolutions kept the Institute from branching into geology or natural history, or from diluting its energies in other movements unrelated to its primary goal. It was on his recommendation that conversation meetings were begun, in the mode of the Royal Society of London. Bache first suggested that the Institute begin meteorological observations. Espy became chairman of the committee appointed to carry on the research, but it was Bache who was responsible for linking the Institute's efforts with those of the American Philosophical Society.

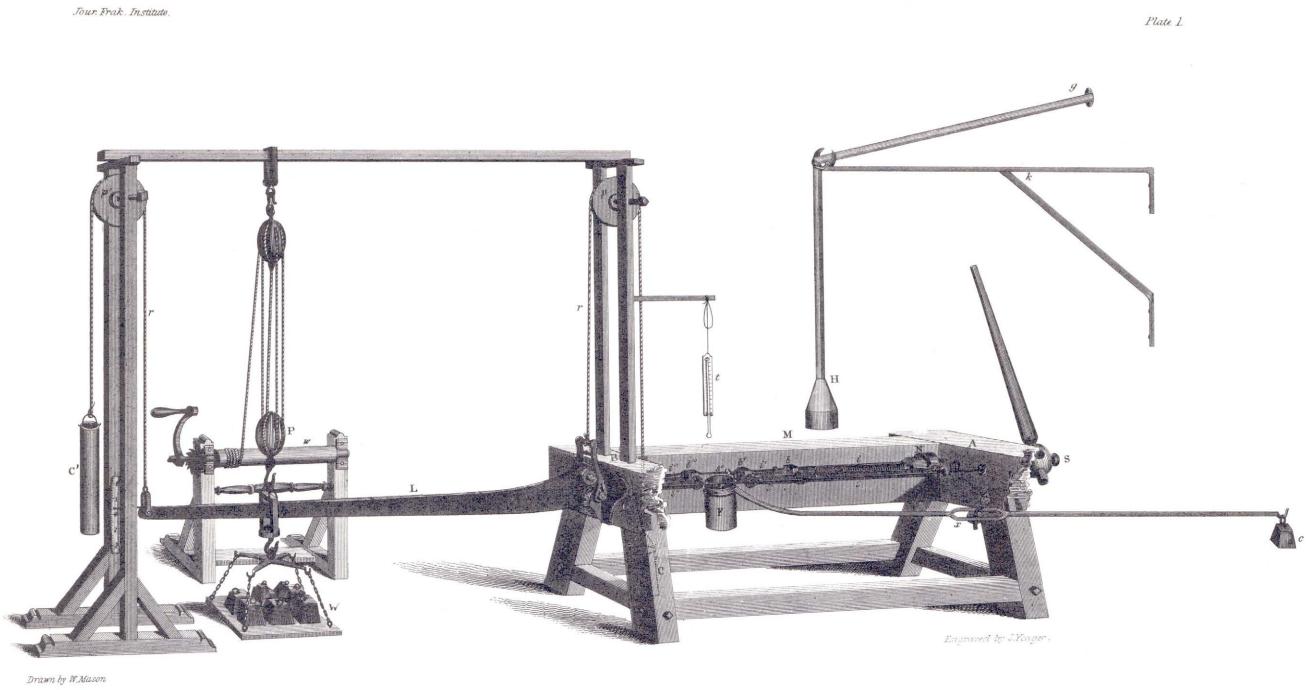
Besides the water wheel experiments, the steam boiler inquiry, and meteorological research, Bache was also the primary figure in another important Institute project. In 1833, the state legislature drafted a bill for a uniform system of weights and measures. The Institute was requested to consider the subject generally, and to make recommendations on the proposed bill. Bache was named chairman of a committee to take up the issue. A

[18] Merle M. Odgers, *Alexander Dallas Bache: Scientist and Educator, 1806-1867* (Philadelphia: University of Pennsylvania Press, 1947), is the best current biography.

study was made of the systems employed in England, France, and by the federal government. As a result of the investigation the committee drew up an alternative bill which the legislature adopted, asking the Institute to supervise the construction of a system of standards for the Commonwealth's weights and measures.

Not long after the study of weights and measures was begun, Bache was also involved in a major reorganization within the Institute. Early in 1834, Merrick proposed to the Board of Managers that the Committee on Inventions be replaced by a Committee on Science and the Arts. Bache seconded the motion and a series of resolutions, drawn up in advance, were passed by the Board to effect the change. In his report as chairman of the Board of Managers in January, 1834, Bache suggested the reason for the change. The Institute's fiscal organization and its economy as "a body politic" probably could not be improved, Bache noted. However, he continued, "your Board are of opinion that such is not the case with arrangements for the scientific labours of the institution," and the Committee on Science and the Arts was proposed to remedy the defect. In essence, the resolutions adopted by the Board provided for wider participation in the Institute's investigatory activities by making membership in the new committee unlimited; gave the committee greater autonomy than that enjoyed by any other committee; and vested in it primary responsibility for the Institute's scientific labors. While the new committee still held the responsibility of the old committee to examine new inventions, the transformation was complete. The 1825 Committee on Inventions which had provided the initial mechanism for special investigations was now, in a new form, the organization's scientific arm, empowered to make whatever investigations it chose and charged in its efforts to sustain "the scientific character of the Institute." Bache was chosen as the first chairman of the Committee on Science and the Arts and held the position until 1836 when he left for Europe.

Of all of Bache's activities within the Institute, his leadership of the investigation into the causes of steam boiler explosions best illustrates the commanding role he played in the organization's research. From the very beginning he dominated the inquiry. At the first meeting of the committee, for instance, Bache's name was attached to every one of the motions which set the committee into operation. While Keating was the committee's chairman for the first year and a half, it was Bache, often as not, who made the committee's report at meetings of the Institute. As chairman of the monthly conversation meetings, Bache made boiler explosions the principal topic of discussion. And when the Secretary of the Treasury wrote suggesting cooperation in a course of experiments, it was Bache's outline of research which was adopted. He was the only choice for the chairmanship of the project when Keating resigned in January, 1832.



MACHINE FOR PROVING TENACITY

Testing machine designed and used by the Institute's Committee, 1832, at the request of the Treasury Department of the United States to report on explosions of steam boilers and the properties of the materials employed in their construction.

IV. THE INVESTIGATION

Most of the time from the inauguration of the steam boiler investigation until January, 1831, was taken up with collecting information and constructing the test apparatus. At that point the research was divided. The sub-committee headed by Johnson was appointed to carry out experiments on the strength of materials. The research on steam boilers remained the responsibility of the sub-committee which had drafted the original plan of research, with Bache as chairman. Keating acted as chairman of the general committee, as has been noted, until the following January when Bache assumed that post. Minutes from the general committee still exist, covering the period to January, 1831. Beyond that, direct information from the general committee or either of the sub-committees is not available. A brief chronology of the research can be sketched out from minutes of meetings of the Board of Managers, however, and the printed reports of the sub-committees and the general committee describe in detail the nature and results of the experiments which were performed.

During the course of the year 1831 Bache's sub-committee held meetings three times a week, and in January, 1832, he reported that they were progressing "as fast as the nature of their duties would admit." Funds from the Secretary of the Treasury began to come in to the committee in 1832 to cover past expenditures, and from then on the committee apparently began to forward bills on a regular basis. In April it was reported that the testing machine for the strength of materials experiments had been obtained and set up in the Institute's hall. The committee was diligently at work but offered gladly to try the strength of any materials which members might care to bring in. Work continued steadily through the next three years with no mention of any special occurrence.

The sub-committee on steam boilers completed

their experiments first. On June 17, 1835 it was reported to the managers that they had presented their report to the general committee and that the Secretary of the Treasury had authorized five hundred copies to be printed. The committee employed the printer of the Institute's *Journal* but he failed to fulfill the engagement. Another printer was engaged, with unavoidable delay, however, and the report was not issued until early in 1836. With permission from the Secretary of the Treasury it was also printed serially in the *Journal of The Franklin Institute* for January, February, March, April, and May, 1836.[19] The report contained descriptions of the test apparatus, a statement of the experiments planned, and an analysis, with conclusions, of each of the experiments.

Strength of Materials Report Delayed

With the publication of the first of the sub-committee reports, it became important to conclude the strength of materials experiments and prepare the report of that sub-committee. Logically, the reports of the sub-committees, containing the details of the experiments and their results, would then be followed by the general report of the whole committee, summarizing the entire investigation and concluding with recommendations based on the research.

Johnson's report, however, was late in coming and the result was an unfortunate controversy. When the first sub-committee report was completed late in May, 1835, Bache had written the Secretary of the Treasury, Levi Woodbury, to make arrangements for printing it.[20] At that time he evidently suggested that the report of the sub-committee on the strength of materials would shortly be completed. Johnson took exception to what he believed was an unwarranted interference in the affairs of his committee and he penned an angry letter to Woodbury defending the length of time which might still be necessary to finish his work, implying at the same time that he had originated the research himself. It was an ill-considered reaction since Bache, as chairman of the investigation, was perfectly within the bounds of his authority to discuss any part of the research. Woodbury responded as the protocol of the situation would normally have dictated: he sent a copy of Johnson's letter to Bache asking for an explanation. Bache's response was succinct. He quoted two resolutions passed by the general committee to the effect that all of the chairman's correspondence had the committee's sanction, whereas Johnson's letter was unofficial, and that while the Institute was responsible for initiating the strength of materials research, it was not "indissolubly connected with the main questions to be solved" and no delay in publishing the first report need result.

When the first report was published in January, 1836, even with a six-month delay at the printers, Johnson's report had still not been written. By April the boiler explosions committee was instructed "to report forthwith" to the Board of Managers the results of the strength of materials experiments. In June, Bache reported to the Board that Johnson's absence from the city prevented any action. Johnson was still out of town in July, and Bache was again compelled to inform the Board that his committee had been unable to comply with their instructions and that since Johnson had all the papers in his possession, no other sub-committee member could make up the report.

The Six-Year Study Completed

Johnson's delay is partly understandable. He was at that point involved in the preparations for the Wilkes Expedition, but the uncertainty of his position may well have made it difficult for him to resolve his other difficulties. Bache, however, was also in a difficult position. Under the circumstances there seemed little reason to delay preparation of the general report of the investigation, and by September it had been presented, approved, and sent to the printers. In December Johnson was given an ultimatum. The Board of Managers requested Bache to write Johnson, requiring him either to make his report or turn the minutes of the experiments over to the Institute. Three weeks later the report was presented to the Board and the Secretary of the Treasury had instructed the committee to print three hundred and fifty copies.[21] The

[19] The full title as printed is *Report of the Committee of the Franklin Institute of the State of Pennsylvania, for the Promotion of the Mechanic Arts, on the Explosions of Steam Boilers. Part I. Containing the First Report of Experiments made by the Committee, for the Treasury Department of the U. States.* (Philadelphia: John C. Clark, 1836.)

[20] The steam boiler research ultimately spanned the careers of three secretaries of the Treasury. When Ingham resigned from Jackson's cabinet over the Peggy O'Neill Eaton affair, Louis McLane took his place. He was in turn replaced by Woodbury, under whose direction the investigation was concluded.

[21] Johnson's report was serially printed in the *Journal* of the Institute for February, March, April, May, June, July and August, 1837, and separately issued under the title: *Report of the Committee of the Franklin Institute of the State of Pennsylvania on the Explosions of Steam Boilers, of Experiments made at the request of the Treasury Department of the United States. Part II. Containing the report of the sub-committee to whom was referred the examination of the strength of the materials employed in the construction of Steam Boilers.* (Philadelphia: Merrihew & Gunn, 1837.)

Franklin Institute's investigation into the causes of steam boiler explosions was completed, over six years after it was begun.

Despite the controversy surrounding its completion and publication, Johnson's report was a noteworthy piece of work. His experiments conclusively demonstrated an important relationship between temperature and tensile strength of boiler materials. He discovered that copper decreased in "tenacity" steadily and markedly with an increase in temperature. Iron, on the other hand, actually increased in tenacity when subjected to temperatures up to about 600°F. Beyond that point strength materially decreased. Johnson examined a large number of iron samples, both from domestic and foreign makers, and his tests showed that the quality of iron not only varied widely from manufacturer to manufacturer, but also that the method of manufacture was crucial to the metal's durability. The experiments also demonstrated that techniques of boiler construction, especially with regard to riveted joints, were an equally critical issue in the safety of steam boilers. Taken together, the reports of the two sub-committees were an impressive statement of the Institute's ability to conduct sound research, equal in sophistication and thoroughness to any similar course of experiments, foreign or domestic. They provided all the experimental data necessary for a resolution of the problem of steam boiler explosions.

The General Report

Alexander Dallas Bache's *General Report on the Explosions of Steam-Boilers* had a different function from that of the sub-committee reports. As chairman of the whole investigation, it was Bache's responsibility to state the nature of the inquiry, summarize the experimental data, and make the recommendations necessary for legislative action. His report was meant to encompass the whole problem and to provide answers which were as definitive as possible. Even given the discursive nature of nineteenth-century prose, the report outlines in a crisp, methodical fashion the major causes of boiler explosions.

Equally important, in Bache's mind, was to show "what are certainly not causes," and one of his objects was to lay to rest conclusively the variety of popular notions which existed on the subject. A catastrophic theory of explosions was probably the explanation most widely believed. It fitted the seemingly instantaneous nature of explosions and was somehow appropriate to their disastrous consequences. There were two such theories, both based on the premise that a low water supply allowed the sides of the boiler to become overheated. Some held that in such a case water added to the boiler to replenish the supply was decomposed into hydrogen on striking the heated metal, creating an explosive mixture. The other theory was that hot steam produced by contact with over-heated metal was the real problem and that water injected into a boiler filled with hot unsaturated steam was suddenly flashed into highly elastic steam.

Both theories were proved unsound. Overheated metal from a low water supply was indeed a cause of explosions, but Bache's report showed where the danger was and the best means of overcoming it. The report included an analysis of various safety valves and devices, contained advice on the design, materials, and construction of steam boilers, and provided information for proper maintenance and safety checking procedures.

Much of this information was made gratuitously available to steamboat operators and manufacturers of steam engines and was in complete harmony with the Institute's aim to advance the mechanic arts. The committee entertained no doubts, however, of the necessity for regulation in the interest of public safety, or of the power of Congress to pass appropriate legislation.

Blending Practice and Theory

One of the outstanding features of Bache's *General Report* was just that quality of balance which the committee's stand on the private versus the public interest illustrates. It was also a nice blend of the practical and the theoretical. The information which served as a basis for legislation, or which would assist the manufacturer and steamboat owner in improving his operation, was direct and entirely practical.

On the other hand, the report was also a clear analysis of the current state of a problem which had engaged scientific men in Europe as well as America. Theoretical knowledge of the properties of steam and of heat was just as much a part of the investigation as careful experimentation, and Bache's report bristles with the footnote documentation which was required to set the committee's labor in the proper intellectual framework. There was no question of the report's theoretical soundness, just as its practical value was obvious. It was also cast in near-perfect form to secure legislative action. The report was complete and thorough. The problem and its solutions were clearly outlined and

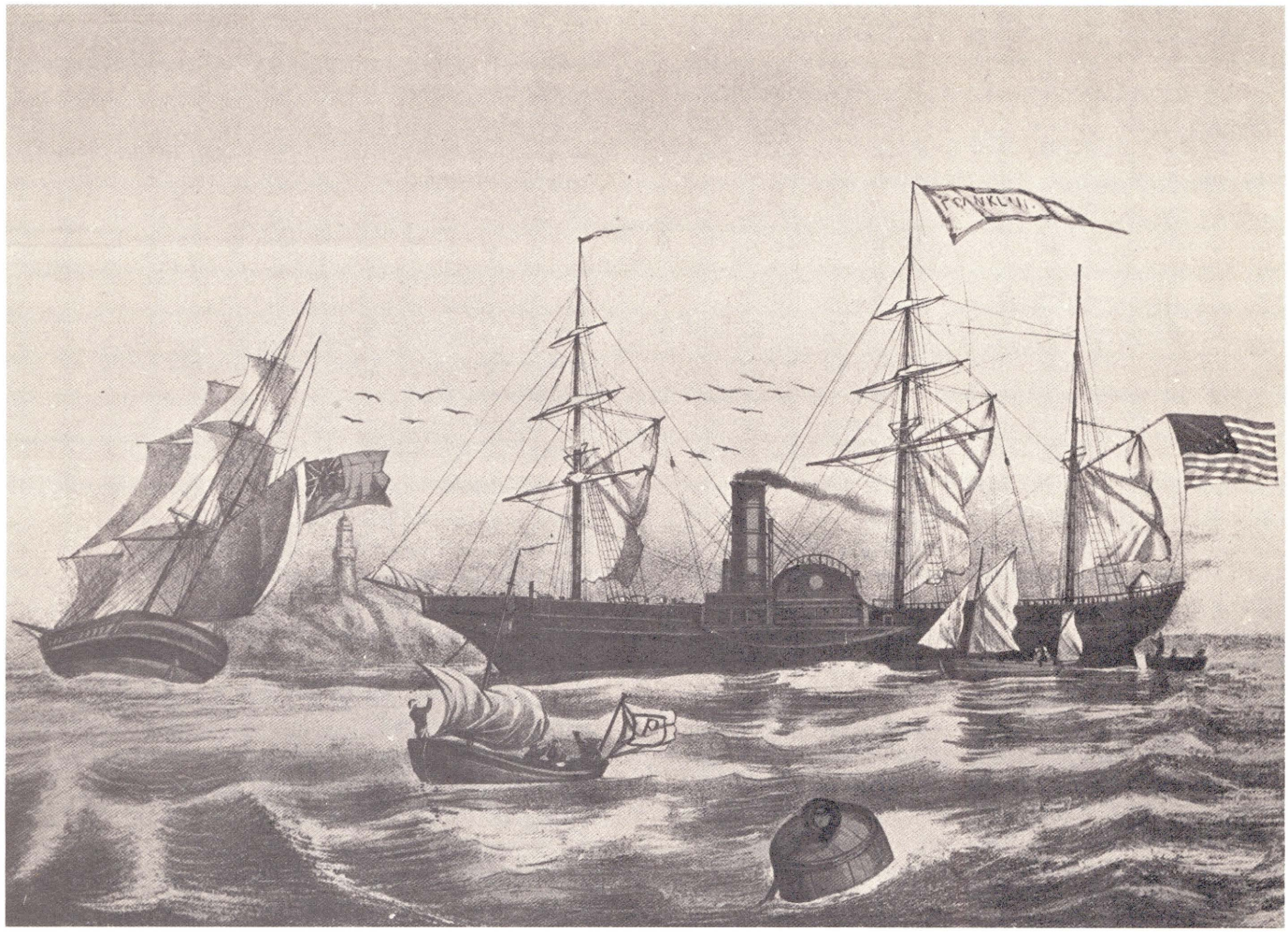
firmly supported. It was an authoritative document, and complete even to the point of including at the end a bill which if enacted would provide the necessary regulation. Bache understood the role of science administrator long before he was appointed to head the U.S. Coast Survey.

Finally, the *General Report* of The Franklin Institute's investigation into the causes of steam boiler explosions is historically significant. The inquiry was the capstone of a series of scientific and technical triumphs by a young and vigorous organization. When Bache's report was published, the Institute had celebrated its tenth anniversary only two years earlier. Yet in that time the society had developed a highly respected scientific and technical periodical, had initiated important research, and had become a consultant to both the state and federal government in matters that were of wide public concern.

As the most ambitious and successful of its early research projects, the steam boiler investigation set the tone and standard for future Institute research. It established the precedent for governmental support of the organization's research—a precedent which was to have considerable application in years to come.

The boiler inquiry also helped fix the character of future investigations. In succeeding decades, the Institute's managers purposefully sought to guide the organization's research efforts into areas of public service and public interest. In contrast with the vast scale of contemporary research projects, the Institute's boiler explosion investigation may seem quaintly limited and archaic. In the context of its time, however, the research was a major accomplishment for American science and of fundamental importance in shaping future research at The Franklin Institute.

COURTESY THE MARINERS MUSEUM



V. NEW PATTERNS FOR SCIENCE IN GOVERNMENT

When The Franklin Institute's investigation into the causes of steam boiler explosions was concluded, the federal government was provided with all the information it needed for the proper regulation of disasters such as the *Helen McGregor*.

The experiments were unique; there had never before in America been a similar research project. To the experimental data, the reports also added the observations of individuals long connected with the steamboat industry, accounts of explosions from eyewitnesses, and the theoretical conclusions of scientists from this country and abroad. Bache's report, supported by the findings of the sub-committees, gave Congress the best informed opinion available on the causes of boiler explosions. The bill appended to Bache's report also provided the government with a concisely stated set of measures to prevent future disasters. In essence, Bache proposed regulations in three broad categories: the establishment of an inspection and certification system; minimum standards for safety devices, operating procedures and personnel qualifications; and penalties for improper operation or non-compliance with any of the bill's provisions. The bill, Bache's report, and the experimental findings of the Institute's investigation were all available to Congress by the early part of 1837.

Legislature Slow to Act

Congressional action was slow in coming, however, and then it was ineffectual. In addition to reports it received from the Secretary of the Treasury, continuing the investigation Ingham had begun, the House of Representatives appointed a committee of its own body in 1836 to consider the subject.

That committee took no significant action and the Institute's reports also remained unused for the rest of 1837.

While Congress vacillated, the explosions continued. It had always seemed true that a particularly violent accident was necessary to stir governmental sensibilities and late in 1837 another serious explosion caused President Van Buren to urge Congressional action. In the Senate, Van Buren's appeal fell on responsive ears, and a bill was reported out of committee. The Institute also continued its efforts. At a Board of Managers meeting on December 20, 1837, five members were appointed to write in support of the committee's bill, which was passed in January, 1838. In the House, however, no action was taken. Then in April, 1838 the crack, new steamer *Moselle* exploded at Cincinnati with the loss of over a hundred and fifty lives. The *Moselle* disaster was particularly noteworthy because of her captain's flagrant disregard for safety, and the House of Representatives was finally moved to action. Legislative delays prevented debate on the bill until June, but it was passed in July.[22]

Congress Balks at Strong Controls

In its original form the bill was similar to the measures suggested at the end of Bache's report. In both the Senate and the House, however, the unsettled issue of the government's ability to regulate private commerce led to an emasculation of some of its most significant provisions. Standard criteria for inspections were eliminated, as was the provision that steamboat engineers possess certain qualifications. Penalties against racing were also struck out. The bill did provide that a boiler explosion was *prima facie* evidence of negligence, in the event of damage suits, reflecting the general Congressional mood that private industry should regulate itself.

With an ineffectual law, however, that hoped-for enlightenment never materialized. Instead an increasing number of disasters vindicated the unhappy prediction made at The Franklin Institute in 1830 that an even greater loss of life and waste of property would result from unregulated steamboat operation. During the course of the next decade, deaths from steamboat boiler explosions were double that of the two previous decades, and effective regulation seemed no closer than when the Institute began its investigation. The findings of the Institute's inquiry were widely available, however, and notwithstanding a hesitant Congress, they eventually played a role in the final development of effective steam boiler legislation.

As early as December, 1838, only months after passage of the bill, the Secretary of the Treasury again reported to the House of Representatives on the subject of boiler explosions. The Secretary's report noted the "very valuable papers on the nature and properties of steam, and the strength of boilers" submitted to Congress by the Institute, and reprinted several letters which expressed disappointment with the legislation which Congress had just passed.[23]

In time, the seriousness of the problem brought new calls for revised or additional legislation. Early in 1848 the Senate directed the Commissioner of Patents, Edmund Burke, to advise it whether or not a revision of patent laws might effect a prevention of boiler explosions, and requested him to submit such additional information as might be relevant. In the Commissioner's judgment, the problem was not to be solved by modification of the patent laws. There was no doubt in his mind of "the propriety and necessity" for legislation, but a knowledge of why explosions occurred was the only sure basis for their prevention. "The question of the causes of steam boiler explosions, if ever solved," the Commissioner noted, "is to find its solution in the researches of men of true science, conducted by the order of the government and at its expense."

That had already been done. "The most valuable contributions to our knowledge of the causes of explosions have been made by the scientific labors of the committee of The Franklin Institute, undertaken at the request and prosecuted at the expense, so far as the apparatus was concerned, of the Treasury Department in 1831." Burke quoted extensively from the Institute's investigation in his report, especially on the causes of explosions, and he urged republication of the whole inquiry. Perhaps to effect that end, at least in part, he included in an appendix abstracts of Bache's general report and Johnson's report on the strength of materials.[24] The entire Institute investigation was not reprinted, but when the Senate ordered ten thousand copies of Burke's report, the effect was nearly the same.

[22] Here again, the best account of the development of federal boiler regulation is Professor Burke's article "Bursting Boilers and the Federal Power," already cited.

[23] *Letter from the Secretary of the Treasury . . .* December 13, 1838 (House of Representatives Document No. 21, 25th Congress, 3rd session).

[24] *Report of the Commissioner of Patents, to the Senate of the United States, on the subject of steam boiler explosions* (Senate Executive Document No. 18, 30th Congress, 2nd Session, Washington, December 30, 1848.)

Institute's Proposals Finally Accepted

Four years later, in 1852, effective steam boiler legislation was passed by Congress. Final victory was the result of several factors. Continued steamboat disasters only highlighted defects in the 1838 bill and made the need for new legislation even more obvious. With increased knowledge and experience in steam engine technology, a larger number of engineers were aware of the regulations needed to solve the problem. Finally, the evidence from all sides was too overwhelming for Congress to admit any longer that the issue was outside its proper authority. In that respect, the Institute was twenty-two years ahead of Congressional thinking.

But Bache's committee had done more than champion the cause of government intervention. The Institute's investigation had provided both the expertise and a rational program for solving the problem of boiler explosions. The committee's three reports, printed separately, published in the *Journal of The Franklin Institute*, reprinted in other periodicals, both in this country and abroad, abstracted, and republished in that form, received an extremely wide circulation. When the time came, the information was available and that was the Institute's signal contribution. As late as 1872 the Secretary of War could write of the Institute's steam boiler inquiry:[25]

> It is gratifying to know that the experiments which have led to the most reliable information hitherto possessed by the scientific world on this difficult subject were instituted and conducted by an American institution (The Franklin Institute of Pennsylvania), under the patronage of our government, over thirty years ago.

The value of the Institute's investigation had always been recognized by those able to judge its merits. From the Secretary of the Treasury, the Commissioner of Patents, and the Secretary of War, the work had received plaudits, as well as from other highly placed governmental figures. Its worth was similarly recognized by manufacturers, engineers, and mechanics who were concerned with the problem of boiler explosions. When the *Moselle* blew up, for example, a local committee was formed to investigate the cause of the disaster. The committee published its findings two months later, the basis for which was "the very able Report of the Committee of The Franklin Institute of Pennsylvania on the same subject."[26]

As late as 1878 the Institute investigation continued to serve as a guide for an understanding of boiler explosions. In that year, an analysis of a Cambridge boiler explosion called the Institute inquiry "altogether the most extended and thorough experiments in relation to the causes of explosion ever made."[27]

The men who carried out the Institute's investigation never meant it to be a series of theoretical researches. The experiments and their evaluation depended on a sound understanding of science, but the aim of Bache's committee was always to provide practical, directly usable information. In that respect, their efforts were best rewarded when republished by magazines of applied science, or when utilized by governmental and private agencies whose interest was the solution of the same problem.

A Trans-Atlantic Controversy

However, the investigation involved prominent figures in American science who were concerned for their country's scientific reputation. That concern was especially acute with regard to British opinion, and when a London editor mishandled Joseph Henry's summary of Bache's *General Report*, the matter became a trans-Atlantic controversy over the form and content of American science and research.

Henry sailed for a European tour in February, 1837. While in London he was requested to write an article on the Institute's investigation. Early in May he wrote his wife that he "was very much engaged in preparing an analysis of the experiments and reports of the Franklin Institute of Phila. on the bursting of steam boilers to be published in one of the Scientific Journals of this city." After "several days assiduous labor" Henry had completed the analysis to his satisfaction and given it to the printer.[28] The journal in question was the *Magazine of Popular Science and Journal of the Useful Arts*, published in London for two years by J. W. Parker. Parker had previously published an abstract of the first sub-committee report and was in the process of preparing another based on Bache's *General Re-*

[25] Quoted in Thomas Coulson's "The First Hundred Years of Research at the Franklin Institute," *Journal of The Franklin Institute*, CCLVI (July, 1953), 8.

[26] *A Report on Explosions and the Causes of Explosions, with Suggestions for their Prevention; Prepared at the Request of the Citizens of Cincinnati* (Cincinnati, 1838), 29.

[27] J. R. Robinson, *The Cambridge Boiler Explosion* (Boston: A. Williams & Company, 1878), 36.

[28] Joseph Henry to Harriet Henry, London, May 9, 1837. Joseph Henry Private Correspondence, Smithsonian Institution Archives.

port. He had received the October number of the *Journal of The Franklin Institute*, containing the first installment of the report, but bad weather had apparently delayed shipment of the remaining installments. The offer of a "friendly *Savan*, who has recently landed in this country from the United States," resolved the editor's dilemma. Henry was "thoroughly acquainted," according to Parker, "with all the proceedings on this important inquiry," and he had written an analysis of the *General Report.*[29]

Bache had preceded Henry to Europe earlier in the fall, and when they met in London he warned Henry of the potential danger in dealings with Parker. There was just cause for Bache's concern. In his first account of the Institute's research, Parker's tone was sometimes sarcastic, and he completely misunderstood an important point in the inquiry. One of the more creative accomplishments of Bache's sub-committee was to determine that fusible alloys, used either as a plate in the boiler or as the link in a safety mechanism, were subject to the effect of pressure as well as the effect of heat. The alloy's function, of course, was to melt at a given temperature, triggering an alarm or opening a hole in the boiler. Bache's sub-committee discovered, however, that steam pressure within the boiler could force out of the alloy those elements with lower melting points, thus altering the compound and consequently its effectiveness as a safety mechanism. To solve the problem Bache proposed enclosing a fusible link within a hollow metal tube so that it would be subject to temperature but not pressure.

Bache and his committee understood the nature of heat transfer but Parker did not. He derided the idea of enclosing an alloy within a protective tube:[30]

> We cannot help thinking that the following parallel case of a 'true remedy' would be prescribed by this sub-committee, if the question were presented to them. Suppose a man has a box which can only be opened by a certain crooked sixpence; what is the best way of being sure to have the sixpence always at hand when wanted? Answer: shut it up in box! —*Enclose the metal in a case!*

While in his introduction and conclusion, Parker had favorable comment for the Institute's labors, his remarks at other points displayed an unnecessary condescension. The tone of his article was not such as to inspire confidence in American hearts.

Henry exacted a promise from Parker that the analysis of Bache's *General Report* should be printed as written or else returned, and under those circumstances he delivered the manuscript to Parker. The editor, however, lived up to all of Bache's worst fears. Henry's article was printed in a bowdlerized form with all the notes cut out. To make matters even worse, Parker claimed in his prefatory remarks that he had only eliminated those passages which Henry had inserted in a naive attempt "to make us *eat our own words.*"[31] The issue, according to Parker, was the "morbidly exquisite" sensitivity of Americans to foreign criticism. Both Bache and Henry, obviously enough, felt differently.

Henry left London for Paris before his analysis was printed. Bache was still in the city, however, and when he learned of Parker's conduct he wrote to Henry: "Instead of returning to me your paper according to your direction to him he has published it in a mutilated form, cutting out the pungent part, reflecting in a balderdash way upon brother Johnathan's thin-skinnedness, etc., etc."[32]

In an attempt to save Henry's paper, Bache prevailed upon Sir Charles Wheatstone, the eminent English scientist, to call upon Parker for a retraction. Parker told Wheatstone that since the article was already in type he was unable to make alterations, and it was printed. Bache then suggested to Henry the possibility of publishing the analysis in another English periodical, but the damage was already done. To William Hamilton, Actuary of the Institute, Bache wrote: "The journal is below contempt & has done itself no good by this affair."[33] He was right again; Parker's magazine failed after publication of the fourth volume.

Despite the tone of Parker's comments, there was genuine English interest in the Institute's experiments. *The London Mechanics' Magazine* also printed extracts from the investigation's reports, making knowledge available on a problem which concerned Englishmen just as it did Americans.

A Turning-Point in Institute Development

Even before it was completed, the inquiry into the causes of steam boiler explosions had a profound influence on the Institute's development.

[29] *Magazine of Popular Science and Journal of the Useful Arts*, III (London, 1837), 321.

[30] *Magazine of Popular Science*, II (1836), 119.

[31] *Magazine of Popular Science*, III (1837), 322.

[32] A. D. Bache to Joseph Henry, London, June 7, 1837. Joseph Henry Papers, Smithsonian Institution Archives.

[33] A. D. Bache to William Hamilton, London, June 26, 1837. Franklin Institute Archives.

Financial support of the project opened vistas of research opportunities which had not before seemed possible. The prospect of shaping governmental policy in scientific and technical matters was equally stimulating.

These two factors marked the future course of research at the Institute. Both the weights and measures study and the Institute's meteorological research show how the organization wished to function in relation to the state. The Pennsylvania legislature had originally approached the Institute in 1833 for its advice on a standard weights and measures bill already drafted. Instead of acting in a secondary advisory capacity, however, the committee, under Bache's direction, studied the systems of Britain, France and America and then submitted an entirely new bill to the legislature.

The weights and measures study illustrates one half of the relationship; the Institute would serve as an objective source of special information. The other half was that the Commonwealth would support Institute research which had application on a state-wide basis. Although no one ever set it out in those terms, the Institute's leadership clearly had an exchange in mind. When meteorological research was begun at the Institute, the Pennsylvania legislature was memorialized for funds to establish a network of weather observers, whose collected and analyzed data would provide important information for the state's agricultural and commercial interests. In 1837 the state appropriated the funds, discharging, in a sense, the obligation it had incurred with the weights and measures study.

Continuing Involvement in National Problems

An even greater potential for the Institute's influence loomed on the federal horizon. Successful conclusion of the steam boiler investigation enhanced the Institute's reputation with the federal government as a source of expertise. In 1837 the Secretary of War requested the organization to conduct a study of building stone from Pennsylvania and Delaware quarries for use in the construction of breakwaters and other public works. In the same year the Secretary of the Treasury asked for information on telegraphic communication.

The response to his request reflects the eagerness of the Institute's leadership to function as the federal government's scientific and technical advisor. Within five days of the Secretary's letter, the Committee on Science and the Arts had prepared and transmitted a complete report on a recommended telegraphic system, setting forth transmission times, the manpower required to staff it, and details of construction and cost.

In the years that followed, the Institute continued to respond to federal appeals. When one of the new twelve-inch guns on the *U.S.S. Princeton* exploded during a trial cruise, the Institute was asked to conduct an investigation of the disaster, which killed the Secretaries of War and Navy as well as several others.[34] To perform the investigation, the Institute again used the strength of materials machine which had been constructed for the steam boiler investigation. The organization also became involved with another steam inquiry for the government in 1864, cooperating with the Navy Department and the newly-created National Academy of Sciences. In these investigations, and others like them, the Institute effectively functioned as a consultant for the federal government, even though it had no official status as such. It was not alone in this respect; other private societies sometimes acted in a similar capacity before the government developed its own research capabilities.[35] In the Institute's history, however, the critical point is that *in the first ten years of its life* it developed the urge, talent, and reputation to serve in that capacity. And more than any other single activity, it was the research into the causes of steam boiler explosions which was responsible for that development.

An Effective Institution

Bache and his colleagues realized that the organization needed a clientele if it was to function as an effective scientific and technical institution. (Not clients in the usual sense; the Institute gained no revenue from the boiler investigation beyond the cost of apparatus.) What they recognized was that the organization's existence depended upon the utilization of its services. Funds for research were not incidental in an organization which had always to struggle for its financial life, and the Institute's leaders sought links with government at all levels for the support it needed.

Bache and his like-minded associates sought more than financial aid, however, and to realize their aims, they fashioned an organization which went far beyond popular lectures for local me-

[34] For an account of the *Princeton* disaster see Lee M. Pearson "The Princeton and the Peacemaker: A Study in Nineteenth Century Naval Research and Development Procedures," *Technology and Culture*, VII (Spring, 1966), 163-183.

[35] For a full treatment of government science see A. Hunter Dupree, *Science in the Federal Government: A History of Policies and Activities to 1940* (Cambridge: Harvard University Press, 1957).

chanics. Nothing reveals the ambitions they held for the Institute so well as the closing comment in the Board of Managers quarterly report for April, 1834. Noting that the organization was simultaneously entrusted with significant responsibilities by the city, the Pennsylvania state legislature, and by the Treasury Department of the United States, the report concluded that those services reflected "the high estimation in which the disinterested labours of the institution are held, as well at home as abroad, throughout our own State and by our Countrymen."

Bache and his group wanted nothing less than national prominence for the Institute. They were ambitious young men and they used the Institute as a vehicle for their aspirations. In the process they transformed the organization, shaping the course of research at the Institute for years to come. When the investigation into the causes of steam boiler explosions was begun, the institution was only on the threshold of a research career. By the time the inquiry was concluded, The Franklin Institute was firmly established as the nation's foremost scientific and technical society.

GENERAL REPORT

ON THE

EXPLOSIONS OF STEAM-BOILERS,

BY A COMMITTEE OF THE

FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS.

PHILADELPHIA:
C. SHERMAN & CO., PRINTERS, 19 ST. JAMES STREET.
1836.

ENTERED, according to the Act of Congress, in the year 1836, by

THE FRANKLIN INSTITUTE,

in the Clerk's Office of the District Court for the Eastern District of Pennsylvania.

GENERAL REPORT

ON THE

EXPLOSIONS OF STEAM-BOILERS.

Report of the Committee of the Franklin Institute, &c., on the Explosions of Steam-Boilers. PART II. *Containing the* GENERAL REPORT *of the Committee.*

THE Committee appointed "to examine into the causes of the explosions of the boilers used on board of steamboats, and to devise the most effectual means of preventing the accidents, or of diminishing the extent of their injurious effects," respectfully submit to the Board of Managers of the Franklin Institute the following report:

The Committee undertook the task imposed upon them by the Franklin Institute, with a deep sense of the responsibility which it involved. On the one hand, a series of disasters by which human life was sacrificed, called loudly for an investigation of the causes which produced them; on the other, an untimely or ill-directed interference with a branch of industry, which has been a source of unparalleled advantage to our country, was truly to be deprecated.

Emanating from an Institute "for the promotion of the Mechanic Arts," the Committee felt advantageously situated. They could not justly be suspected of a desire to trammel the progress of any art; and yet the public confidence, which had always been accorded to the institution, would naturally attach to a committee selected by it.

The Committee further believed that the apprehensions of the public, aroused by the frequent recurrence of accidents, could only be satisfactorily allayed by an investigation, which would show that such accidents were not unavoidably incident to the useful agent which they distrusted, but resulted from a want of due regulation of its power, or from circumstances incidental to its use which could be foreseen, and therefore guarded against. If disappointed in this anticipated result of investigation, the Committee hoped to satisfy those who are public carriers, that it was their duty to provide protection for those who trust life in their hands, against an agent thus found to be uncontrollable.

With these views the Committee commenced, actively, the collection of information upon the subject intrusted to them. The replies to their circular were canvassed in their meetings, and finally laid before the public.*

* As these replies will be frequently referred to in what follows, it is proper to state here, that the references are made to the pamphlet distributed by the Committee to their correspondents and others, and that Nos. I. to XIII., both inclusive, were pub-

It occurred most opportunely for the ultimate success, though not for the rapid completion of their labours, that an opportunity was afforded them for experiment, by which to test many of the suggested causes of, and preventives to, the explosions of steam-boilers.

These experiments, originally proposed by our public-spirited fellow-citizen, S. D. Ingham, Esq., then Secretary of the Treasury of the United States, have been brought to completion and presented to the public under the auspices of the present Secretary.*

The Committee trust that they have, by the experiments just referred to, shown not only what are some of the causes of explosion, but, which is quite as important, what are certainly not causes. In this way they hope to have turned away the attention of ingenious men from false hypotheses which cannot furnish the remedies they are in quest of, and to have pointed out some directions in which their labours may be profitably bestowed.

A desire to complete the reports upon their experiments, has induced a delay in the present report, which, thus far, however, the Committee are satisfied will be found to have been judicious. This conclusion they rest upon the many references, which will appear in the following pages, to those experiments, which have given an authority to recommendations and suggestions, that could not have been claimed for them unless thus strongly supported by facts.

They regret much that the part of their report referring to the strength of materials will, from circumstances, be unavoidably incomplete. This deficiency they hope will hereafter be made up, the experiments on the subject having been some time since concluded; and they do not feel warranted, by this cause, in any longer delaying their general report.

In this report the Committee have endeavoured, by examining the different accounts of explosions on record, and the writings on collateral subjects, to ascertain what causes have been operative in producing these disasters. The difficulty of procuring satisfactory testimony in regard to them, has been often pointed out. Most frequently those from whose mismanagement or want of vigilance they have immediately resulted, have been victims to them, and when they have survived, the precise state of things before the occurrence was imperfectly known to them; and, however honest, their minds have received a bias towards the non-existence of certain circumstances judged likely to have produced the results.

It hence follows that in regard to many explosions, either none of the circumstances which immediately preceded them, and bearing upon them, are known, or by inaccurate statements of them, an appearance of mystery is thrown around the whole matter, calculated to baffle research, and to alarm the community, who are exposed to a recurrence of the same dangers. Thus it happens that of the numerous explosions on record, few are made to subserve the cause of humanity, by a knowledge of their proximate causes. The details of the number of killed and wounded, and of the more or less entire destruction of the boilers and of the boats, are given in the daily prints, and public curiosity is satisfied.

In making their examination, then, of the cases of explosion, the Committee have selected such as they have found most directly to the points

lished in the "Journal of the Franklin Institute of Pennsylvania for the promotion of the Mechanic Arts," Vol. VIII.; Nos. XIV. to XXVIII., both inclusive, in the same Journal, Vol. IX.; No. XXVIII., part second, and XXIX., in Vol. X.; and No. XXX. in Vol. XI.

* Hon. Levi Woodbury, for whose promptness in forwarding their views, the Committee beg leave here to return thanks.

in support of which they are cited; omitting others in which the facts are less clearly made out, or in which the causes assigned may be resolved into matters of opinion. Having themselves no theory, or theories, to support, they have of course not been biassed, by such views, in the selections made.

This mode of proceeding is, obviously, not calculated, by one effort, to exhaust a subject. But the Committee believe that they are able to make a decided step forward in the knowledge at present existing, in a connected form, on this subject. That to the causes pointed out by a Committee of the British House of Commons,* in 1817, namely, improper construction or material of a boiler and undue but gradual increase of pressure, they will be able to add others as important, and as fully proved as the former. Nor will any cause for alarm result from this extension, since it will be found that it is only ignorance of these circumstances which constitutes their danger, and that they may be prevented from occurring and remedied when they occur. It will be full time after the well-ascertained causes of explosion have been duly guarded against, to look for others more occult in their nature, if indeed there are such.

In the following Report, the Committee propose to examine separately the circumstances which they consider as the proximate causes of explosions in steam-boilers, and the preventives or remedies which have been proposed to meet them. Under each division of the subject they will make the suggestions or recommendations to constructors and others, which they base upon the previous discussion; and at the close of the Report, will present a project of a law for carrying into effect, in regard to steamboat boilers, those recommendations which are of primary importance.

It will be observed thus that while they do their duty to the arts by pointing out as far as their knowledge extends what they consider improvements or valuable alterations, they do not propose to render imperative any measures but such as are required for public safety.†

In submitting this project the Committee obviously do not entertain a doubt of the competency of Congress to legislate on the matters embraced in it. The several discussions in that body on the subject,‡ the recommendation of the President of the United States,§ and especially the very detailed provisions of the bill recently proposed in the Senate, fully sustain them in this opinion. They consider the question now to be, not whether any regulations may be made, but how those to be made may be rendered most efficient and complete. For this completeness the very respectable Committee‖ who reported the bill referred to, in the Senate of the United States, have expressed themselves anxious; and the labours of this Committee, so far from being an interference, will, no doubt, as far as they may be approved, be looked upon as forwarding the views thus expressed.

* Charles Harvey, Esq. Chairman.

† This project is put forth with a view to free discussion, without which the Committee would feel entirely unwilling that it should be adopted. They propose, with this view, to distribute it as widely as possible, and invite especially a discussion of its provisions, in the Journal of the Franklin Institute.

‡ See Act regulating steam vessels, proposed in 1824, mainly founded on the action of the Committee of Councils of Philadelphia; and especially the Report of Mr. Wickliffe, from a Select Committee of the House of Representatives, May 1832. [Pub. Doc. Rep. No. 478.]

§ In the annual message for 1833.

‖ The Committee on Naval Affairs. Hon. Samuel L. Southard, Chairman.

The good effects which have attended the adoption of partial preventives in England, and the excellent effects from the more complete ones in France, should urge us, as Americans, to do our part in preventing further destruction of life and property by these disastrous explosions. And while we apply means for this purpose, experience and reason both teach us that they will produce no undue or severe restraints upon mechanical skill or commercial enterprise, but rather that they will aid both, by increased confidence on the part of the public.*

The Committee propose to investigate the different causes of the explosions in steam-boilers under the following general divisions.

I. Explosions from undue pressure within a boiler, the pressure being gradually increased.

II. Explosions produced by the presence of unduly heated metal within a steam-boiler.

III. Explosions arising from defects in the construction of a boiler or its appendages.

IV. Explosions resulting from the carelessness or ignorance of those intrusted with the management of the steam-engine.

V. An examination of the particular cases of collapse of a boiler, or its flues, by rarefaction within.

I. Explosion from undue pressure within a boiler, the pressure being more or less gradually increased.

1. This is one of the most natural causes to look to as producing the bursting of steam-boilers, and one which, probably, is as frequently operative as any other. It might be supposed that with a safety-valve always applied and a mercury gauge so easily applicable, the low pressure boiler should have been exempted from explosion. But such has never been the case, and we find a select committee of the British House of Commons, in 1817, specially directing their inquiries to the cause above-stated, as producing the disastrous explosions which, even at that day, called for legislative interference.

2. That a gradual increase of pressure can produce all the effects of the most violent explosions, may be inferred from many cases on record, attributed with probability to this cause; and was proved conclusively by the direct experiments of this committee. In these latter, cylinders of copper and iron were violently torn asunder, the parts thrown from their places, scattering the materials of the temporary furnaces over which they had been heated, and of the fire, to considerable distances.† There are

* Professor Silliman, in an article on the safety of steamboats, has the following strong expression of opinion: "The boat which is first ascertained to afford absolute security will be a fortune to its proprietors."—Silliman's Journal, vol. xix. p. 146.

† This effect is well illustrated by the rending of a copper cylinder just referred to. The subjoined figure and extract are from the first part of the Report of the Committee on Explosions, &c. p. 68. (Journ. Franklin Institute, vol. xvii. pp. 224, 225.)

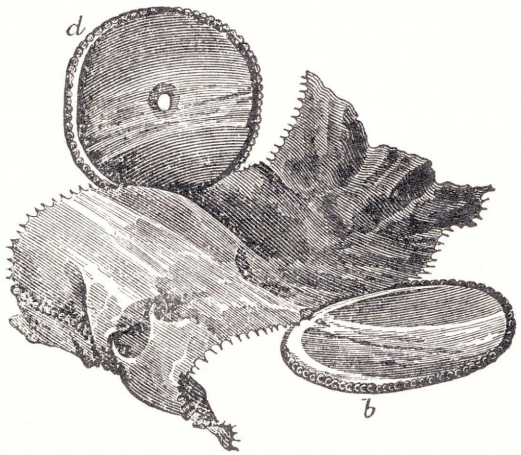
"As before, nothing remarkable occurred previous to the instant of explosion, and the members of the committee, employed in the experiments, were engaged in observing the boiler at the instant it exploded. A dense cloud of smoke and flame, capped by steam, rose from the pit; the stones and combustibles were widely scattered, and the boiler was thrown, in a single mass, about fifteen feet from the furnace. The noise attending this explosion was like that from the firing of an eight inch mortar.

"The boiler was rent as shown in the accompanying figure, giving way in an irregular line, just above the probable water line on one side of the boiler, but not conforming to it. *d* and *b* were the lowest points in the two heads before the explosion.

also cases well made out in which a weak place in a boiler has acted as a safety valve, but such fortunate circumstances are not always to be looked for, and better methods have been devised of effecting the same object, than to imitate them by the use of thin plates. The idea stated to be current,* namely, that a boiler does not explode if duly supplied with water, is wholly untenable and highly mischievous in its tendency.

3. We are warranted, then, in looking to the failure of the apparatus designed to prevent undue pressure, or to the misuse of it, as the cause of explosions of the most violent kind. The current of testimony is too strong to permit the former view to the exclusion of the latter. It has been too clearly shown that those who have charge of the steam engine sometimes not only neglect the means of safety provided, but actually render them inoperative. Not to multiply instances, the Committee refer to the following as entirely well made out, and in which the connexion between the misuse of the means of safety and the explosion is fairly to be inferred. First; That of a cast-iron boiler used in a sugar-house in Wellclose-square,† London, the mercury-gauge attached to which was plugged up and the safety-valve purposely overloaded at the time of explosion. Second; The case of a steam tow-boat on the Rhone,‡ in France, when

The sheet of copper was torn from the heads, unrolled and irregularly bent, adhering to the heads for only a short distance near the top of each; and the heads were



bent outwards. The thickness of the copper along the line of rupture varies from 0.25 to 0.35 of an inch, and the metal appears to have been highly heated at one end of the torn portion."

* Replies to Circular of Com. on Explosions, &c. No. XII. Report of Thos. Bakewell, Esq.—"at a subsequent period and after the captain had conversed with some of those who contend that a boiler cannot burst with 'fair play,' as it is termed."—To meet this prejudice, the Committee have chiefly selected their proofs from accidents which have occurred abroad.

† Minutes of evidence before a Select Committee of the House of Commons, &c. &c. by Geo. Dodd, Civ. Eng. Evidence of Mr. Braithwaite, Mr. Richter, &c. Also, Partington on the Steam Engine.

‡ Annuaire du Bureau des Long., 1830. p. 141. Journ. Frank. Inst. vol. v. p. 401. It is stated in the London Journ. of Arts, that the pistons of the engine had become fixed in the cylinders, by being expanded more rapidly than these latter, and that Mr. Steele the manufacturer of the engine supposed the steam to be insufficient, and was induced by the desire to have his engine succeed, to adopt a device which resulted so fatally. Lond. Journ. Arts, vol. xiii. p. 346.

the safety-valves of the four boilers were fastened down, so as to be immoveable. Third; The explosion in one of Trevithick's locomotives,* when the safety-valve was kept down to raise steam at starting. Fourth; The explosion in the steam carriage of Messrs. Burstall and Hill,† when in going over a soft piece of road, in which the coach laboured, the engineer kept down the safety-valve, by pressing upon the lever. And fifth; The explosion of the boiler of the steamboat New England from a "pressure of steam, produced in the ordinary way, but accumulated to a degree of tension which the boilers were unable to sustain."‡

4. If the apparatus devised for the low-pressure boiler has been rendered inoperative, the high-pressure boiler has had to contend with peculiar difficulties. No gauge applicable to it has yet been brought into use. The open gauge must be of undue height, or cumbrous in its serpentine form; and the closed gauge requires great nicety in construction, and a correction for the temperature of the air inclosed in it. A graduated safety-valve would give the engineer desirable information, and has been to a certain extent used. The engineer of a locomotive engine, where the spring weighing machines are used with the safety-valves, has it in his power to ascertain at any moment, the pressure within the boiler.

He has it is true besides, the power of keeping the valve down even when the pressure within may be unsafe, but then he and his assistants would probably be the only victims of its abuse.

5. The extraordinary and fatal increase of pressure which the Committee have above shown to be produced designedly at times, has at others been attributed to the adhesion of the safety-valve. A practical engineer, Mr. John B. Calhoun, has given a remarkable instance of this kind§ as occurring to a safety-valve on the boiler of the steamboat Legislator, then navigating the Hudson. The mercury-gauge indicating an undue pressure within the boiler without the rising of the valve, the engineer endeavoured first to raise it by a cord which passed into the fire-room: failing in this he went to the top of the boiler where the valve was, and moved the weight upon it towards the fulcrum, but without effect. He then applied his force at the end of the lever to raise it, when suddenly the valve opened with a loud report, and the flow of steam commencing lasted some time before the elasticity had diminished to its usual degree.

6. In this case, there can be but little doubt that the valve had corroded upon its seat or was fastened by the drying of oil, or other matter, to it. The carelessness of the fire-man who had charge of the boiler, and whose duty it was probably to raise the valve from time to time, is fully proved by his allowing the steam to get so high, that the rod of the mercury-gauge

* Minutes of Evidence, &c. Evidence of Mr. Chapman.

† Reply to Circular of Com. on Explosions by L. Hebert, Esq. of London, No. II. See also the bursting of one of Hancock's boilers, from the fastening down of a safety-valve. Lond. Mech. Mag. vol. xviii. and Journ. Frank. Inst., vol. xi. p. 277.

‡ The part marked with inverted commas is the conclusion drawn by an able committee who investigated the cause of this explosion. It is unpleasant to see in this case, how those concerned in the press of steam, were biassed in their views given to the committee and communicated, as the committee testify, as honest convictions, and without intention to deceive. The engine-men were not injured by the explosion. The form of these boilers was no doubt defective, and one part of them will be commented on hereafter. The two boilers exploded almost simultaneously.—Journ. Frank. Inst. vol. xiii. pp. 55 and 126.

§ Account of an extraordinary adhesion of the safety-valve of the boiler on board the steamboat Legislator, on the Hudson. By the Engineer. Journ. Frank. Inst., vol. v. p. 355.

was against the boiler-deck, without giving notice to the engineer. Had not the latter observed, from the rapid working of the engine, that the steam was high, and investigated the matter, the lives of many would no doubt have been sacrificed.

7. The experiments made by M. Clement Desormes* on the tendency of disks, when placed in front of an aperture, through which air is forcibly issuing, to approach it, led him to condemn the safety valve entirely, and especially the disk form. This sentence does not seem to the Committee to be just,† since the tendency upward, under the most favourable circumstances to its action, is very limited in amount, and may easily be counteracted by a device, which will lessen the acting weight, when a safety valve is raised. Besides, the proportion which the area of the disk bears to that of the aperture materially affects the amount of this tendency, and is, in practice, very much less than was used in the experiments of M. Clement. The ingenious experiments of M. Hachette and of Messrs. Hopkins and Roberts of Manchester, have shown the truth of these remarks.‡ If, however, this action were allowed to have full effect, by dimensions in the valve expressly intended to produce it, an increased area of valve would entirely obviate the objection. Different effective means of lessening the acting weight, on the rise of a safety valve have been used or proposed, such as that employed by MM. Arago and Dulong§ in their experiments, on the elastic force of steam at different temperatures, or the very similar one, described by Mr. L. Hebert in his interesting communication to this Committee.‖ In them the weight rolls towards the fulcrum when the valve opens.¶ The Committee apprehend that this form although very effective while in order, would tend by disuse to lose its power of action. They would prefer, in practice, a construction similar to the second form proposed by Mr. Hebert in which the lever being curved effects the same object, while the weight is not required to be moveable. They intend to recommend a suitable form of lever of this kind.

* Notice in Franklin Journal vol. iv. p. 97. See also explanations of the phenomenon offered by Jacob Perkins, Esq. in the same volume p. 252, and in Lond. Jour. Arts, vol. xiii. p. 275. By Doct. Hare in Jour. Frank. Inst. vol. ii. p. 58. By James P. Espy, Esq. in the same vol. p. 59, and by Asa Spencer, Esq. in the same vol. p. 61. also remarks on p. 203.

† In this view the Committee coincide entirely with M. Arago. See Annuaire du Bureau des Long. 1830, p. 157, and Jour. Frank. Inst. vol. v. p. 408. In fact the committee named in the next note did not sustain the deduction, above referred to in the text, remarking, in very guarded terms, that the limits within which the phenomenon occurs were not then sufficiently known, to decide upon the possibility of an accident from it.

‡ M. Hachette who investigated this subject shows in a strong point of view the effect of the relative proportions of the disks. When one is not many times the other in size it is impossible to satisfy the conditions of the problem. Annales de Chim. et de Phys. vol. xxxv. p. 44, &c. The Committee who examined this subject in its relation to the Steam Engine, consisting of MM. Biot, Poisson and Navier, made an experiment in which with a disk, nearly six times the diameter of the opening, and a pressure of steam of about 2.8 atmospheres, the tendency to adhesion when the disk was .01 of an inch from the opening, was but half a pound. Annales de Chim. et de Phys. vol. xxxvi. p. 70. In the experiments of Messrs. Hopkins and Roberts, with an excess of pressure in the effluent air of .05 of an atmosphere, over atmospheric pressure; the total tendency to adhesion at its maximum, was but .005 of an atmosphere, with an opening of $2\frac{3}{8}$ inches, and a disk of six inches in diameter. With a disk of eight inches in diameter the total tendency was increased from 32 oz. avoirdupois, to 48 oz: and with disks of $4\frac{1}{4}$ in. diameter and under, no such tendency was manifested, the aperture of efflux remaining the same. Manchester Trans. vol. v. N. S. and Jour. Frank. Inst. vol. x. p. 188.

§ Annales de Chimie et de Phys. vol. xliii.

‖ See replies to circular of Com. on Explosions, No. XI.

¶ In that of MM. Arago and Dulong there was also an arm projecting on the opposite side of the fulcrum from that on which the weight keeping down the valve was placed; upon this a weight rolled from the fulcrum on opening the valve.

The practice of passing the stem of a safety valve through a stuffing box, as it is calculated entirely to defeat the object of the valve, should never be allowed. In fact the more open to inspection all the parts of the apparatus are the better. If it is necessary to carry off the steam from that which the engine-man has the control of, it can be accomplished without resort to packing.

9. There can be no doubt that the form of the safety-valve materially influences the certainty of its action. Although the disk-valve was early recommended, the nicety of workmanship required to make it tight has limited its use, and perhaps the experiments of M. Clement have produced a prejudice against it. The cone, which is in common use, may be more easily tightened when imperfectly fitting the seat; but this very fact is an objection to it. No pressure can cause the disk valve to prevent the escape of steam, if the valve and seat be clean, unless they have been ground to fit. The committee adopted this form of valve in their experiments,* and in no instance was undue adhesion observed. Throughout their experiments, the pressure of the steam corresponding to the opening of the valve with its different weights, was noted by the steam-gauge, or by the temperature of the water within the boiler. No means were used to keep the valve in other than what might be considered fair working order, but when, from the action of dirt, it had become leaky, the grinding upon the seat was very easily performed, and restored its efficiency. Two valves of the same form were used, and the comparison of the calculated pressures due to the weight upon the valve, with the observed pressures at which the valve rose entirely, or leaked so badly as to require additional weight, uniformly gave the former in excess. The average ratio in the experiments was 1 to 1.035, the former number representing the observed, and the latter the calculated, pressure.

10. These conclusions are sustained, in a general way, by the success which has attended the recommendations of the select committee of the British House of Commons. The law, based upon their investigations, requires that there should be two safety-valves upon every boiler, one of which is out of the control of the engineer,—and further provides a penalty for the overloading of either valve, by any person whatever.†

11. In addition to two safety valves, the regulations for the safety of the steam engine in France, require two fusible plates or plugs, of suitable diameter, to be attached to every boiler. These plugs are intended to act by the heat of the inclosed steam, and to give way when it has reached a certain point. In the application of them which we are now considering, they are exposed to a pressure corresponding to the temperature, and in order to prevent them from giving way, as they verge towards the fusing

* Report of Com. on Explosions, part I. pp. 71, &c. Jour. Frank. Inst. vol. xvii. p. 228.

† The regulations relating to the safety-valves of steamboat boilers are as follows:

That every such boiler shall be provided with two sufficient safety-valves, one of which should be inaccessible to the engine-man, and the other accessible to him and to the persons on board the packet.

That the inspector shall examine such safety-valves, and shall certify what is the pressure at which such safety-valves shall open, which pressure shall not exceed one-third of that by which the boiler has been proved, nor one-sixth of that which by calculation it shall be reckoned to sustain.

That a penalty shall be inflicted on any person placing additional weight on either of the safety-valves.

Of twenty-three witnesses, practical engineers and others, examined by the Parliamentary Committee, seventeen recommended explicitly the additional safety-valve, out of the control of the engine-man.

point, they are covered with wire, or with perforated disks or gratings of metal.

12. This mean of safety was made the subject of elaborate experiments by this committee.* The result was, that when alloys of tin, lead, and bismuth, such as are used for fusible plates, are exposed to heat and pressure, parts of them soften at temperatures below that at which the entire plate would become liquid. Being exposed to pressure, these fluid parts are forced out,† leaving a less fusible mass. In one case described by the committee, this operation was carried so far before the plate gave way, that, from a plate melting at 254° to 275° Fahr., was produced a mass fusible only at 312° to 345°. One part of the alloy which oozed out was found to melt at 223° and another at 233°.‡ To this action a fusible plug would be also exposed, and the committee are of opinion that no method of application in which pressure acts upon these compounds, can be efficient in practice.

In the experiments referred to, the plates being thin, were generally burst by pressure; not, however, acting precisely as thin plates of copper or iron would have done, but being partially softened by heat.

13. While the committee deem it very desirable that a convenient steam gauge applicable to high pressure boilers should be devised,§ they

* Report of the Com. on Explosions, of the Franklin Institute, Part I. p. 23. "V. Inquiry in relation to plates of fusible alloys." Jour. Frank. Inst. vol. xvii. p. 74.

† This fact, but to a limited extent, seems to have been noticed by M. Gualtier de Claubry, who did not, however, follow out the suggestion. Receuil Industriel, 1829.

‡ The entire series of conclusions from these experiments, which formed one of the most interesting branches of the committee's investigations, are as follows:

"The conclusions deduced from the foregoing experiments, on metallic alloys, may be thus stated.

"1st. The impurities of common lead, tin, and bismuth, are usually not such as to affect materially the fusing points of their alloys.

"2d. When mixed in equivalent proportions, tin and lead formed alloys, not presenting the characters of distinct chemical compounds, in definite proportions. The alloys between the range of one equivalent of tin, to one of lead, and one equivalent of tin to six of lead, varied considerably in the interval between the temperature of commencing to lose fluidity, and that at which a thermometer, immersed in the solidifying metal became stationary. These different alloys produced nearly the same stationary temperature in a thermometer plunged into the solidifying metal.

"3d. Fusible metal plates covered by a perforated metallic disk, and placed upon a steam-boiler, show signs of fluidity at the disk, before the steam has attained the temperature of fusion of the alloy of which the plate is composed. This fluid metal oozes through the perforations in the disk, and the plate thus loses much of its substance before finally giving vent to the steam.

"4th. The under parts of the plate are not kept from fusion by a protecting film of oxide there formed.

"5th. The thickness of the plate is not important, provided only that it is sufficiently strong to resist the pressure of the steam at temperatures below its point of fusion.

"6th. The temperature at which the plates are cast, and the rate of cooling of the cast metal, do not affect the temperature at which the plates give vent to steam.

"7th. The effect stated in conclusion third, is explained by the nature of the alloys used, which are formed of portions of different fluidities; the more fluid parts, are forced out by the pressure of the steam, leaving the less fusible. These latter in general are burst, not melted.

"8th. By pressure in a receptacle provided with small openings, this effect of separating the differently fluid portions of an alloy, may be imitated.

"9th. Fusible alloys, used to indicate the temperature of any part of a steam-boiler, should not be exposed to the pressure of the steam; at least not in such a way that the separation of the differently fusible constituents of the alloys may be effected."—Report of Com. on Expl. Part I. p. 34, and Jour. of Frank. Inst. vol. xvii. p. 84.

§ The Committee regret that the hydrostatic safety-valve of Mr. Ewbank has not

consider that until this is done, a substitute should be furnished in a graduated safety-valve, marked with numbers expressing directly in pounds to the square inch the bursting* pressure of the steam, and within the control of the engine-man. This would act as a convenient, and, for practice, a sufficiently exact method of knowing what he ought always to be informed of, the bursting pressure in the ordinary working of the boiler. Besides this, however, there should be a lock-up valve, for the original weighting of which there should be a proper responsible agent, and which should be capable of being raised by the engine-man, but not of being kept down. With a valve of this kind of sufficient dimensions, of proper form, and duly weighted, the Committee believe that danger from gradually increasing pressure might be entirely avoided.

A thermometer suitably graduated and passing into the steam or water of the boiler, would prove, under ordinary circumstances, a useful gauge, and may be conveniently applied as described in a subsequent part of this report.

14. With a view to meet the dangers which have been discussed in this section, the Committee would make the following recommendations, the means of carrying out the principal of which, by law, will be found suggested at the close of the report:—

First. That every boiler be provided with two safety-valves, each of which shall be competent to discharge the steam, made in the ordinary working of the engine. The first of these valves should be graduated by the maker of the engine, and have stamped upon the lever by which it is weighted, the bursting pressure at which it will open, by calculation, when the moveable weight is placed at the several notches. The pressure corresponding to the last notch to be equal to the bursting pressure, under which the engine is to work. The second valve to have a weight fixed immoveably upon it, the pressure of which upon the seat, together with that of the atmosphere upon the valve, is equal to the working pressure of the engine. This valve should be so arranged as to admit of raising, but not of placing additional weight upon it. To this end it should be inclosed. The rise allowed by the inclosure should rather exceed half the radius of the valve seat.

Second. The Committee recommend to constructors the disk valve. The diameter of the disk should not exceed once and a half that of the valve seat, as a less ratio than this will leave sufficient margin, and any sensible tendency to close from the effect of the issuing current will certainly be avoided.

Third. That a cord be attached to the lock-up valve, by which it may be raised at the same time with the free valve. And that the working of each be ascertained at least every two hours.

Fourth. That an open mercury-gauge be provided for each boiler of every engine not carrying more than two atmospheres of working pressure. The height of the mercury to be indicated by a float which shall truly mark upon a graduated scale the bursting pressure in inches.

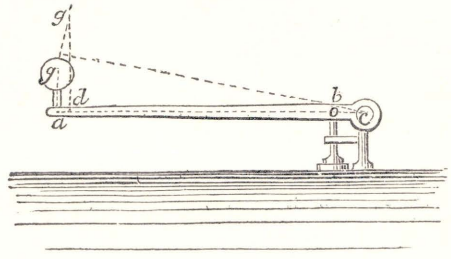
For high-pressure boilers they recommend the thermometer, graduated

been brought into use. It would answer, by a slight modification, as a gauge, and no doubt can exist of its being applicable to the stationary engine. The oscillations of the liquid may interfere with its operation on board of steamboats, but to what extent the Committee are not prepared to say. See description and figures Jour. Frank. Inst., vol. ix. p. 64, and vol. x. p. 2.

* This term is used to signify the excess of pressure of the steam within, over atmospheric pressure, in contradistinction to the *working* pressure, which is used to express the total elastic force of the steam.

to show the pressures corresponding to the temperatures of saturated steam, as a convenient gauge.

Fifth. That the lever of the lock-up valve be bent upwards at the end, so that in rising it shall relieve the valve of part of the weight. A suitable proportion for such relief would be about one-tenth of the pressure derived from the weight, and the height of the bend above the lever should be regulated to meet this.



The lever would have a form similar to the annexed. The part *a g*, which is turned up, may be straight or otherwise. The adjustment should be made so that *d c* is nearly nine-tenths of *a c*. *g* being the centre of gravity of the ball, lever, &c. will lie a little out of the centre of the weight, towards the fulcrum.

Sixth. As there can be no doubt that the competition in regard to speed is, or has been, a strong temptation to an undue increase of pressure by engineers or firemen, it should be expressly prohibited by law.

II. *Explosions produced by the presence of unduly heated metal within a steam-boiler.*

15. In a properly constructed steam-boiler no part of the metal is exposed to the direct action of the fire without being immediately in contact with water: the temperature of the metal cannot be raised above that of the water, and is thus determined by the weight upon the safety-valve. When, from any cause, the metal is not so circumstanced, it becomes unduly heated, and danger may arise from two sources; first, the metal is weakened and rendered less capable of resisting even ordinary pressure; second, it serves as a reservoir of heat ready to bring into existence highly elastic steam, whenever water shall obtain access to it.

16. The first of these positions rests upon the basis of direct experiment, and is, the Committee believe, generally admitted.* Their experiments on the strength of materials have, however, developed a curious fact in regard to the strength of malleable iron, namely, that it slowly increases at first with an increase of temperature, and attains its maximum at a temperature above that at which any of the steam-engines used in practice, are worked. Above this maximum, the decrease of strength is very rapid; so as to be, at a red heat, but about one-sixth of that at ordinary temperatures. Copper, on the contrary, is weakened by any increase of temperature above the lowest, which was tried, namely, 32° Fah. The fact just stated in regard to iron, is interesting in its application to the proof of iron boilers, by the water-press, and as showing the great, and rapidly increasing, danger from diminished strength, as the metal is raised above the temperature of maximum strength.

17. Secondly, the heated metal serves as a reservoir of heat to furnish highly elastic steam, when water is in any way brought in contact with it. That highly heated metal can produce steam, rapidly, has hitherto been a controverted position. In the experiments of Klaproth, successive drops of water thrown into an iron spoon, originally heated to redness, vaporized the more rapidly as the metal lost heat. In the experiments of Perkins and others, larger quantities of water in highly heated metallic

* In the minutes of the Select Committee of the House of Commons there is a statement by Mr. John Steel that cast iron is strongest at the temperature of 300°, but it is not supported by reference to experiment.

vessels, vaporized very slowly. It is true that by injecting water into an iron cylinder, heated to redness, Mr. Perkins found a sudden increase of elasticity; but he attributed the effect to the hot and unsaturated steam which the cylinder contained, and through which the injected water passed.* The Committee found that the temperature of clean iron at which it vaporized drops of water most rapidly was 334° Fah.† The developement of a repulsive force is so rapid above this temperature that drops which required but one second to disappear, at the temperature of maximum vaporization, required 152 seconds when the metal was heated to 395°. One-eighth of an ounce of water introduced into an iron bowl, three-sixteenths of an inch thick, and supplied with heat by an oil bath, at the temperature of 546° Fah., was vaporized in fifteen seconds, while at the initial temperature of 507° Fah., that of most rapid vaporization under these circumstances, it disappeared in thirteen seconds. The cooling effect of the water upon the metal is here strikingly shown, by the increased temperature to which the latter has to be raised at the beginning of the experiment, in order to give the most rapid vaporization. A further illustration of the same kind is afforded by comparing the temperature giving most rapid vaporization, when the metal of the bowl is supplied with heat by a good and a bad conductor, or imperfect circulator, as by a bath of tin and one of oil. With a rough surface, an iron bowl one-quarter of an inch thick, vaporized one-eighth of an ounce of water most rapidly by introducing it when the metal was at 555° Fah., the bowl being in an oil bath; while in a tin bath the corresponding temperature was 508° Fah.

18. By carrying out this idea we have the clue to the action of water thrown, in considerable quantities, upon heated metal; and find, accordingly, that when the water was increased sixteen times, or from one-eighth of an ounce to two ounces, the temperature of most rapid vaporization was raised from 460° to 600° Fah.; the surface of the metal being smooth, and the heat supplied through tin. Now although differences in the mode of applying heat will alter these temperatures, it is clear that they rise, rapidly, with the quantity of water thrown upon the metal. In the case where as much water was thrown into an iron bowl as it could contain without loss by ebullition, the temperature of greatest vaporization, upon a clean surface, was 600° Fah. or about 200 degrees below a red heat, and would, according to analogy, have been higher if on a rough, or oxidated surface.‡

19. These observations explain the direct experiments made by the Committee, in which highly elastic steam was always rapidly produced by injecting water into a boiler heated to bright redness.§ In one case, by the injection of ten ounces of water the elasticity of the steam was raised, in less than two minutes, to upwards of twelve atmospheres, and a miniature explosion produced. The remarks made in this experiment show, that wherever the water slid along the bottom of the boiler the spot of contact was for the instant blackened, by the sudden reduction of temperature, and this under the unfavourable circumstance of the introduction of a limited quantity of water. The bottom of the boiler in these experiments was clean, but not bright. The time required for the generation of

* Franklin Journal, vol. iii. p. 418. Lond. Mechs. Mag. or Journ. Frank. Inst. vol. ix. p. 348.

† Report of Com. on Explosions. Part I. "Vaporization of drops." Reply to Query VI. Journ. Frank. Inst. vol. xvii. p. 90.

‡ Report of Com. on Expl. &c. Reply to Query VI. "Vaporization of increased quantities of water." Journ. Frank. Inst. vol. xvii. p. 160.

§ Ibid. Reply to Query II.

explosive steam under these circumstances does not yet admit of calculation, but this may be affirmed with certainty, that a safety-valve which, under ordinary circumstances, may be adequate to carry off the excess of steam produced in a boiler, will prove wholly insufficient for its escape, in the supposed case.

20. These experiments are entirely supported by well authenticated cases of explosions in steamboat boilers. Mr. Bakewell* gives an instance in the case of the steamboat Grampus, where six cylindrical boilers, each thirty-eight inches in diameter, exploded simultaneously. The engineer had discovered that they contained very little water, and had suddenly thrown in a plentiful supply. When one of the boilers of the steamboat Car of Commerce† exploded, it was well known that the pumps had not furnished the requisite supply of water; and just after an attempt to remedy this difficulty, the head of one of the boilers was thrown off. This boiler was, it seems, differently constructed from the others, with which it was connected, and which did not give way.

The first of these cases is distinctly made out and the second cannot be resolved into a matter of opinion, as may perhaps be done with other accidents, which, though there is a strong probability that they are to be traced to this cause, the Committee refrain from quoting.

21. It is, of course, not assumed that an explosion must necessarily follow the presence of heated metal; for other circumstances must conspire to produce such a result. Facts indeed may be brought to show that, in certain cases, these attendant circumstances have been accidentally wanting, or have been judiciously avoided.

As examples of this, may be taken instances mentioned by Col. Long‡ in which timber on the top of cylindrical boilers has been known to take fire, though considerably remote from any fire-flue. Those to which Mr. Bakewell§ has been an eye witness, when the steam has been so highly heated after leaving the boiler, as still to burn the hempen packing of the steam cylinder, and where wood contiguous to the boiler has been fired. Similar incidents not followed by explosions have occurred in the mines of Cornwall,‖ in one of the Liverpool and Dublin packets.¶ Examples of the second kind will be referred to subsequently.

22. With such a powerful agent present, as the highly elastic steam which it has been proved may be rapidly generated by the heated metal, it might have been supposed that no other cause for explosion would have been looked for, than the action of this steam. The case is, however, otherwise, and the Committee must turn aside from their direct course to examine briefly the theory which assigns the production, and subsequent destruction of hydrogen gas, as the cause of the explosion. According to this view, the water thrown upon the heated metal is decomposed, and hydrogen gas evolved; or a similar decomposition of the steam, by the hot metal, takes place. This hydrogen, becoming mixed with oxygen, is ignited by the red hot metal, and an explosion ensues. The diffi-

* Letter to Sec'y. of Treasury, communicated to Com. on Expl. Reply to Circular of Com. No. XII. Also Letter of Thos. J. Haldermann, No. XXI. of Replies.

† Letter of Thos. J. Haldermann, No. XXI. of Replies to Circular, &c.

‡ Replies to Circular, &c. No. II.

§ Replies, &c. No. XII.

‖ Mr. Perkins states on the authority of Mr. Moyle that a ladder accidently resting upon the top of a boiler, was set on fire by heat communicated from thence. Frank. Jour., vol. iii., p. 417, or Lond. Jour. Arts. vol. xiii. p. 95.

¶ Evidence before Com. of House of Commons, 1817. Hazard on Explosions. Frank. Jour. vol. iii. Ewbank on Explosions. Jour. Frank. Inst. vol. x.

culty of furnishing oxygen for the hydrogen to combine with, has lately been met more satisfactorily by Mr. Perkins, than it had been by any preceding theorists. He asserts that air is frequently drawn in by the operation of the forcing pump, and is thus accumulated in the boiler. The primary hypothesis, in regard to the production of hydrogen, having been fully disproved by the experiments of this Committee, there is no necessity for examining the minor ones; it may be well, however, to observe, that if air were introduced into a highly heated boiler, containing hydrogen in too large a quantity either to combine explosively, or silently, with the oxygen of the air, that element would be taken up by the heated metal; and that gases cannot enter, and remain without mixing with the steam, and being carried out with it. In the experiments of the Committee which have been referred to,* water was thrown upon the bottom of a boiler, heated to orange redness, without being decomposed. In fact the scale of oxide existing upon the bottom prevented the decomposition of water, by enfeebling the affinity which would produce it. This boiler was carefully cleaned, and in good working condition; a condition in which no one need be told, a boiler has not a bright metallic surface.

23. Carburetted hydrogen does no doubt exist at times in a boiler, in greater or less quantities, from the decomposition of oil, or of vegetable substances introduced to stop leaks, or to prevent deposites, but nothing warrants the idea that it can accumulate and mix with air, so as to be dangerous.

In furnaces where coal is used as a fuel, it will be seen in the sequel that gas, if prevented from escaping by the closing of a damper, may collect, and may possibly be a source of danger.† The ignition of a mixture of coal gas and air in a furnace has been known to destroy it,‡ as also of a mixture of gas from resinous wood and air; but these are cases altogether foreign from the subject under discussion.§

24. The explosion of the steamboat Enterprise, on the Savannah river, is said to have occurred at the instant the boat was struck by lightning. This has been advanced as confirming the hydrogen hypothesis; but no inference can fairly be drawn from an accident, in regard to which the circumstances are so little known. If there was hydrogen present, there must have been unduly heated metal, and the direct action of electricity on the nonconductors around the boiler, may have so displaced it as to bring water upon the heated metal, and thus to effect an explosion. This, like the other supposition, is mere hypothesis. It is certainly, however, quite as contrary to analogy, that an electric spark should pass through any part of a space, like the interior of a boiler surrounded by a con-

* The reader should refer to these, that he may see the care which was taken in them. A negative result requires so much more caution than a positive one, that more time was devoted to those experiments in order to make them satisfactory than the Committee deemed warranted by the importance of the subject. Report of Com. Explosions, Part I. p. 61, &c. Jour. Frank. Inst. vol. xvii. p. 217.

† Explosion in the Mold mines as given by John Taylor, Esq. Philos. Mag. vol. i.

‡ M. Arago states this to be the fact on the authority of M. Gay Lussac. A furnace was thus destroyed at the Paris arsenal. Annuaire du Bureau des Long. 1830, p. 197, and Jour. Frank. Inst. vol. vi. p. 54.

§ See the case of an explosion of a sheet-iron drum attached to an anthracite stove, with its explanation by Prof. Hare. Jour. Frank. Inst. vol. vi. p. 337. Pine shavings, were used to kindle the fire, the gas, from which mixing with the air in the pipes and drum produced an explosion, when the flame from the kindled shavings rose into it. Refer also to the explosion of the bellows of a smith's forge. Silliman's Jour. vol. xxiv. p. 182.

ductor, and thus explode a mixture of hydrogen and oxygen within it, as that it should shatter this extensive conductor by its direct action. The Committee consider the circumstances of this case as too illy defined to draw any inference from it, certainly not one which is contrary to sound theory, by which they mean general induction from numerous well observed facts.

25. Another case has been urged with much more appearance of directness in the testimony. A boiler in the Union rolling mills at Pittsburgh burst with a tremendous explosion; a cylinder with one of the heads attached, was thrown out of the works, and rising to a considerable height in the air, fell nearly two hundred yards from its former bed. A passenger in a boat which was near at the time, describes a stream of fire, as issuing from behind the boiler, which, according to the hypothesis under discussion, was a stream of burning hydrogen. It is almost needless to remark that if hydrogen had been the cause of the explosion it would not have burned in a stream behind the empty boiler as it rose; the observation is, however, perfectly well explained by Doct. Jones,* by the stream of light which appears to attend every luminous substance moving rapidly, on account of the duration of the impression upon the eye. That the boiler was red hot there appears no doubt.

26. From this digression the Committee return to the pursuit of their subject. They conceive that it has been fully established, that the presence of unduly heated metal is dangerous, both from the weakness of the material, and the possibility of its producing highly elastic steam. They therefore proceed to examine the probable causes leading to this result, and which have been suggested either in the communications made to them or in other documents, and the proposed remedies for, or precautions against, the danger.

27. *First. Unduly heated metal may result from a deficiency of water within a boiler.* This seems to be a frequent and generally acknowledged source of explosion. The forcing-pump, by which a boiler is supplied with water, if at first well regulated, so as to furnish an adequate supply, and if kept constantly in action by the machinery, is subsequently liable to derangement of various kinds. The valves may be put out of order, the passages to or from the pump may be choked by sedimentary, or saline, matter. The pump may in some cases be heated so as to inject steam and not water. Any accident of this sort will cut off the due supply of water, and the level of that within the boiler will be lowered more or less rapidly. This will be true of self-acting as well as of ordinary means of supplying boilers. No one we believe has yet been applied, the working of which can, at all times, be relied on. There are, besides, cases in which the forcing-pump is not in action, when the production and use, or waste, of steam is going forward. In some stationary engines the feeding of the boiler only goes on at intervals, and the due supply is therefore dependant on the attention of the fire-man. The same is true of steamboat boilers when the boat stops at a landing, and indeed the mischief is frequently increased by opening the safety-valve by hand, and allowing the steam, and of course the water, to waste freely. By an approximate calculation† it may be seen that to lower

* Jour. Frank. Inst. vol. iii. pp. 70, 71. "Editor on explosions in Steam Boilers."

† In the case of a cylindrical boiler with an interior furnace and flue, calling l the length of the fire-surface, d the diameter of the furnace, and π the ratio of the circumference of a circle to its diameter, $\pi\ l\ d$ = the extent of fire-surface. Then since in a boiler of this kind 1 sq. foot (144 sq. inches) of fire-surface can convert into steam .356 cub. inches of water, per second; $\pi\ l\ d \times \cdot\frac{356}{144}$ = the number of cubic inches of water vaporized,

the water one inch in a cylindrical boiler with an interior furnace, or in a boiler of the same form where the fire is applied directly to the exterior, and with an interior flue, will require but from five to nine minutes. If by this depression an interior flue of eighteen inches should be laid bare for an inch in depth, between 102 and 103 square inches of surface would be subjected to the action of the fire, for every foot in length of the flue, supposed level.

28. It thus appears that by accident, or in the ordinary management of the steam engine, a deficiency of water may occur, and highly heated metal be produced within a boiler. Recorded instances show that such has frequently been the case.*

29. The metal, then, being softened by heat, may give way to the ordinary working pressure of the steam. This will, of course, depend upon the amount of this pressure, and upon the temperature which the metal has reached. The frequent rupture of boilers near the usual water-line, and in a horizontal plane containing very various thicknesses of metal, would lead us to suspect that this is connected with undue heating, which if all circumstances were equal in the parts of a boiler, would take effect equally, at equal distances from the water-line. But the Committee have not before them any well established instance in which a boiler without interior flues, has exploded merely by the ordinary pressure of the steam, when the boiler had been unduly heated. The case of the explosion of a cylindrical boiler, at the foundry of Mr. McQueen, in New York, may have been an exception to this remark, but the fact of the water having been very low, though rendered probable, is not entirely made out.† The copper boiler exploded in the experiments of the Committee, may be considered, however, as illustrating the possibility of such an occurrence.‡ The explosions in boilers with interior flues, arising from these circumstances, have been found to affect those flues; which "collapse," that is, are crushed, and rent, and are frequently separated from the boiler. The case of the accident on board the steamboat Patriot, which occurred near

per second. Again if we denote by x, the depression of the water level in one second, c the breadth of the water-line, and assume the length of the boiler to be equal to that of the interior cylinder, $x\ c\ l$ will be an approximate value for the quantity of water vaporized. Equating the two values found, and cancelling l, we have $\pi\ d \times \cdot\frac{3\,5\,6}{1\,4\,4} = x\ c$. The depth of water may be assumed at two-thirds the diameter of the exterior cylinder, which, calling D that diameter, gives $c = .98$ D, and $\pi\ d \times \cdot\frac{3\,5\,6}{1\,4\,4} = .98\ x$ D. The ratio of d to D in a number of cases in practice varies from .4 to .6 and even .7; taking the lower limit or $d = .4$ D, we have $.4\ \pi$ D $\times \cdot\frac{3\,5\,6}{1\,4\,4} = .98\ x$ D. Whence $x = .003$ inches per second. Or to lower the level one inch would require 5 mins. 16 secs., supposing the water not to reach the interior flue.

For a cylinder with an interior flue, but where the fire is applied externally, supposing the effective fire-surface to be half that of the boiler, the depression per second, will not be less than two-thousandths of an inch.

* As instances, may be taken, the boiler of the steamboat Huntress, No. VII. Replies, &c. of the Western Engineer, No. II. Replies, &c. Legislator, Eagle, and Massachusetts, No. XVII. Replies, &c. Explosions at Pittsburg, No. XII. Replies, &c. and Jour. Frank. Inst. vol. iii. p. 70.

† Thomas Ewbank "On the Explosion of Steam-Boilers," Jour. Frank. Inst. vol x. p. 3. That the pressure was unusually great, is satisfactorily shown; and with or without undue heating, was, no doubt, the cause of the explosion. In the case of the Etna, the boiler was unduly heated, but, whether it gave way to the pressure, ascertained from the working of the engine, to be lower than usual, or whether water had access to the hot metal, is not known.

‡ Report of the Committee on Explosions, Part I. p. 68. Jour. Frank. Inst. vol. xvii. p. 225.

the mouth of the river Ohio, in 1828, distinctly illustrates this point.* It is stated that the engine was kept in motion after it was known that the water was below the flues; an act of temerity which was followed by the collapse of one of the flues.

30. It is highly probable, as will be seen hereafter, that water is thrown upon the hot metal, in cases where the engine has just been set in motion, or when the safety-valve has been opened, just prior to an explosion, and hence we are not warranted in adducing such cases here.

31. The following, is a well authenticated instance in which the pressure was not sufficient to produce explosion, or in which the metal was cooled by its change of figure, but when the danger was obviously imminent. It was that of the boiler of the steamboat Legislator,† of which an oval flue was flattened by exposure to the steam pressure, when known to be unduly heated. An explosion was avoided by the fire being put out, as soon as the deficiency of water was ascertained.

32. The Committee next proceed to consider the means which have been pointed out, by which, in the event of an undue heating of a boiler, water may obtain access to the heated metal.

Various means by which water may be brought into contact with heated metal, have been suggested. This may occur by the intentional or accidental removal of an obstruction, or by some other repair, to a forcing-pump,‡ or by the injection of water by a hand-pump.§ When it is recollected that one cubic inch of water will produce six hundred and twenty-one cubic inches of steam of three atmospheres, or one hundred and eighty-nine inches of steam of eleven atmospheres, and that this steam is produced far more rapidly than in the usual action of the boiler, we are at no loss to understand that an ordinary safety-valve cannot give vent to it. The explosions on board of the steamboats Grampus, Constitution, &c., should serve as warnings against the introduction of water into a boiler under such circumstances, and the course taken by the engineer of the Legislator as an example to be followed. In this latter case there can be no doubt, from the circumstances stated by Mr. Lester,‖ that an explosion was prevented by cooling the boilers previous to the introduction of water, when the deficiency was discovered. No circumstance of mere convenience, should be suffered to interfere with such a course.

33. A second mean assigned for bringing water in contact with unduly heated, metal, in a boiler is by the foaming produced by the opening of a safety-valve, or in the ordinary working of the engine. This foaming has been abundantly demonstrated, and a detailed statement of the direct experiments made on the subject by this Committee, may be seen in their report to the Secretary of the Treasury of the United States.¶ Since the foaming is

* Replies to Circular, &c. No. XXI. Thomas J. Haldermann, Esq. The explosion on board the Tricolour might be cited as another example. The boat was at rest. No. XXI. Replies, &c.

† Replies to Circular, No. XVII. E. A. Lester, Esq. of Boston.

‡ In the case of the boilers of the Car of Commerce, (No. VII. Replies, &c.) of the Grampus, (No. XII. Replies, &c.,) &c.

§ See explosion of a boiler at Aston Forge, (No. XI. of Replies, &c.) Boiler of the steamboat Constitution, (No. VIII. of Replies, &c.,) &c.

‖ See replies to Circular of Com. on Explosions, No. XVII. Letter of E. A. Lester, Esq., to Sec. of Treasury.

¶ Reply to query first. "To ascertain, by direct experiment, whether on relieving water heated to, or above, the boiling point, from pressure, any commotion is produced in the fluid." See also a paper by Mr. F. Peale, whose observations were contemporaneous

caused by making an opening in the boiler, it may be supposed that it cannot be adequate to do more than to produce steam to supply the place of that which escapes. This view of the subject derives some support from the experiments incidentally made by M. Arago,* and directly with this object by the Committee, but is contradicted by those of M. M. Tabareau and Rey.† In the experiments of M. Arago, the boilers were not unduly heated, in those of the Committee, there was present a considerable amount of heated metal, and in those last referred to, and in which an increase in the elasticity of the steam was produced by opening a safety-valve upon a small boiler, the boiler was surrounded by a charcoal fire. There can be little doubt, then, that the result must depend upon the precise circumstances of the case, and that danger *may* result, though it does not *necessarily* follow, from making an opening in a boiler when the water is low. This effect from foaming would be increased, if, in addition to the agitation produced by the first working of the engine, after stopping, the safety-valve should be opened. This was the common practice on the Hudson, a few years since; the safety-valve being opened, by hand, on putting the boat in motion after the landing or taking up of passengers.

34. The successive explosions of connected boilers such as occurred at the Polgooth‡ mines, and on board the steamboat Rhone,§ are easily explained if referred to the effect of foaming, and difficult to understand on any other principle, since just before the explosion of the second boiler a large opening was made for the escape of steam.‖

35. It has been assumed by our countryman Perkins, in his hypothesis on the subject of the explosion of steam-boilers, that the hot steam formed by contact with unduly heated metal is the true source of danger. This opinion has been shown to be inconsistent with the deductions from sound theory.¶ The injection of water into hot and unsaturated steam, should reduce, not increase, its elasticity. With a view to ascertain if any circumstances had been omitted in the application of theory to this problem, the Committee made direct experiments on the subject. The water was introduced both in a full stream, and through small apertures. In no case, an increase, and in all but one a perceptible decrease of elasticity in the hot and unsaturated steam, was observed. Fourteen ounces of water, injected into steam at 533° reduced its pressure .34 of an atmosphere.** The steam had in this experiment a temperature corresponding to the

with the experiments of the Com. Journ. Frank. Inst., vol. viii. p. 145, and Replies, &c. No. XXI. Potts on Explosions, Jour. Frank. Inst. vol. vi. p. 327.

* M. Arago. Sur les explosions, &c. Annuaire du Bureau des Long., 1830, pp. 148, and 180, and Jour. Frank. Inst., vol. v., p. 404, and vol. vi., p. 47.

† Ibid.

‡ J. Taylor, Esq. "On the accidents incident to Steam Boilers." Lond. Philos. Mag. vol. i., 1827.

§ Annuaire du Bureau des Long., 1830., and Jour. Frank. Inst. vol. v. p. 401.

‖ The same opinion is expressed by M. Aragp, Annuaire, &c. p. 184. Translated in Jour. Frank. Inst., vol. vi., p. 49. The other cases referred to by him, in which an explosion followed the opening of a stop-cock by hand, as at Lyons, or of a safety-valve by the steam, as at Essone, may be explained by supposing the openings insufficient to give vent to the steam, which was produced by the action of the boiler, in the circumstances then existing.

¶ Dulong. Annales de Chim. et de Phys., vol. xlviii.

** In a certain theoretical case, namely, that in which all the heat to vaporize the injected water, is derived from the hot steam, and the quantity of water which that steam can vaporize, without reduction of temperature below that of saturated vapour of the same elasticity, is injected, the precise reduction of elasticity has been calculated by M. Dulong. See Ann. de Chim. et de Phys., vol. xlviii., p. 378.

pressure of sixty atmospheres,* and an actual elasticity of only 6.82 atmospheres. There was besides a fire which supplied heat, as it was absorbed by the vaporization of the injected water.

36. A correspondent has suggested† that when a steamboat is first set in motion, the inertia of the water may cause it to rise at one end of the boiler and then to oscillate, by which it would be thrown upon parts of the boiler which might be unduly heated. This is no doubt a true cause, but it would be difficult to say to what extent it would be effective. The subsequent suggestion that water can take a charge of heat in a latent state, which may be rendered free by mechanical means, the Committee do not conceive to be valid. Experiments which have been referred to as showing this, are fully explicable upon well established principles.

37. There are two other important circumstances to be examined falling under this division of the subject, namely, the effect of the careening of a boat especially one having connected boilers, and the effects of the sudden cracking of deposits of mud or sediment, beneath which the metal is unduly heated. These will, however, be treated under separate heads.

38. The Committee now proceed to examine *the means proposed for preventing the occurrence of the dangerous circumstances now under discussion.* These of course have reference mainly to the original source of the danger, that is to the deficiency of water within the boiler, though an avoidance of the secondary causes might prove effectual.

39. First.—Various self-regulating apparatus for the supply of boilers have been proposed and partially used. Second.—Methods for ascertaining the level of the water or of giving notice when it falls to a certain level are in use, or have been suggested. Third.—Some methods for ascertaing the temperature of the boiler or of particular parts of it, have been contrived.

40. 1st. One of the most common methods of regulating the supply of water to a boiler is by the use of the float. This is understood to have been entirely successful in the low-pressure boiler, the float being applied to raise a valve connecting a reservoir of water with the boiler to be supplied. A self-feeding apparatus in which a float was used was proposed by Mr. Charles Potts,‡ who exhibited to the Franklin Institute a very neat working model, in which a glass boiler was kept at nearly a constant level, by this method. Its application is most difficult in the case of a small high-pressure boiler with interior flues.

Engineers differ very much in the amount of confidence which is to be placed in the float: those who have seen it in operation in the large boiler of a low-pressure engine give it implicit confidence, others who have tried it in the small high-pressure boiler consider its action too uncertain to answer a good purpose,§ even when in its best form. If the objections to the float are not valid, and we apprehend that they are only partially so, the real difficulty will be found to lie in general objections to all self-regulating apparatus. This obviously is one which is liable to get out of order since it communicates between the exterior and interior of a boiler and hence must have a packed joint, liable when the stem is not in con-

* Calculated from the formula deduced by M. M. Arago and Dulong from their experiments.

† Replies to Circular of Com. on Explosions, No. XX.

‡ Journal of the Franklin Institute, vol. vi. p. 42, and also p. 327, &c., where the apparatus is illustrated by a figure.

§ D. J. Burr on the explosion of steam-boilers. Jour. Frank. Inst., vol. vi. p. 335. Mr. Redfield objects to its use in steam boat boilers, see Report to Secy. Treas. U. S. in Doc. H. R., No. 478. session 1831—2.

stant motion to become tight, and therefore beyond the power of the change of buoyancy in the float to move.

41. A most ingenious method of feeding boilers was patented in 1825 by Mr. Eve.* It consisted of a revolving cock, bored in part through, and playing alternately into the boiler, and into a box of water. It was expected that this cock being placed at the proper level of the water within a boiler, would merely draw out and return water while this was at a due height, but when it sunk too low would draw out steam and return water. The difficulty of condensing the high steam† drawn out; and of making the returned water flow out of the openings, seem to have rendered this as well as other promising schemes of the same sort, abortive.‡ An attempt to obviate these objections which was seen by some of the members of this committee was unsuccessful. Mr. Charles Potts§ has recently proposed a plan which is similar in principle. It will have to encounter the difficulty of the flow of water from moderately large openings when the pressure on the two ends of the column is the same, and the necessity for the alternate heating and cooling of the revolving plug or chamber which acts as a feeder, and of at least a part of its contents. They agree entirely, however, with the Committee of Science and the Arts that this principle merits further trial.‖

42. The Committee are decidedly of opinion that no self-feeding apparatus has been, or is likely to be, invented which can be a substitute for the care of an engineer; and, indeed, they consider the carelessness which is liable to result from their use as a very serious, though not an insuperable objection, to them.

43. 2nd. Methods for ascertaining the level of the water in a boiler, or of giving notice when it falls to a certain level.

The imperfection of the gauge-cocks in ordinary use has been often pointed out, and indeed is generally admitted. Originating in the very infancy of the art in Savery's engine, they remain at this day, a stain upon its more mature age. At best,¶ when the water is tranquil within a boiler they only show, roughly, the position of the water-line; and when it is above the highest cock, or below the lowest, they fail entirely; and cannot be placed far apart without making their indications within these limits, too rude even for practice. When a boiler is in action, particularly if it is small and contains high-pressure steam, the foaming is so considerable as to interfere with their use. In the report of experiments by this Committee abundant evidence is to be found of this imperfection; as an example of which may be taken the case, where by raising the safety-valve, of the small experimental boiler, indications of water appeared at a gauge-cock, below which the hydrostatic level was known to be nearly two inches.**

* Lond. Jour. of Arts. vol. xii. p. 230., Lond. Mechs. Mag. vol. vi. p. 344., Rep. Pat. Invent. vol. iii. p. 70. A revolving wheel for the same purpose has been patented by Mr. Jesse Fox. Jour. Frank. Inst.Vol. x. p. 161.

† See also J. S. Williams' patent for supplying boilers with water. Jour. Frank. Inst. vol. vii. p. 183, which though different in action is liable to this objection, in even greater force.

‡ Walker's feeding plug. Trans. Soc. Arts, &c. vol. l. part i, p. 63. Sliding valve and box. Lond. Mechs. Mag. vol. xxi. p. 376.

§ Journal of the Franklin Institute, May 1836. Vol. xvii. p. 302.

‖ Report on a "Plan of a new pump for feeding Steam boilers." Jour. Frank. Inst. Vol. xviii. p. iii, 1836.

¶ From the remarks which follow, exclusive of the objection on the score of the effect of foaming, we must except the shifting gauge-cock of Mr. Philos. Tyler described in Jour. Frank. Inst. vol. xv. p. 178.

** Report of Com. on Explosions, Part I. pp. 11, 12. &c. Journ. Frank. Inst., vol. xvii. pp. 9, 10. Peale on the height of water in boilers of locomotives, Jour. Frank. Inst., vol. viii. and replies No. XXI. Potts on explosions. Journ. Frank. Inst. vol. vi. p. 329.

44. The method of indicating the level of the water by a float* is liable to all the objections urged against the feeding apparatus, depending for its action upon that instrument. It has not, however, except in very rare cases, been used in this country. An alarm float was tried by the Committee, which is not subject to the objection in regard to the stuffing-box, since it is entirely within the boiler. This is by no means a new device,† though the particular arrangement was made by Mr. D. H. Mason for the Committee; and is figured and described in the first part of their report.‡ This device is intended to allow the escape of a small jet of steam whenever the water rises above, or falls below, a determinate level.§ The alarm by the issue of steam through a trumpet tube, being only applicable to engines working at very low pressures, does not require special notice here.

45. With due care on the part of the Engineer, and the Committee are of opinion that no substitute has yet been found for such care, the glass tube affords the best means known to us, for observing the level of the water within a boiler. It seems strange that this excellent device which has stood the test both of experiment and of practice, has met with so limited a degree of favour. In the great progress made, of late years, in the locomotive engine, it has been so clearly shown, that engineers and their assistants, can be induced to employ any machinery, the use of which is insisted upon, that the excuse of their indisposition to change, should not be urged any longer. In this very case, in which the glass tube, is probably more exposed to fracture, than in any other, it is practically used. The objection on the score of its breaking by unequal expansion and contraction of the glass, and of the metal with which it is connected, has been obviated, by passing the ends of the tube into stuffing-boxes; that on the score of its breaking by shocks, by giving it great thickness; and that of its breaking by sudden variations of temperature by using well annealed glass. The difficulty of the glass clouding when high steam is used, by the action of the steam on the alkali, is got rid of by using green glass. The experiments which the Committee made on this apparatus, were highly satisfactory and they confidently recommend its use to practical men.‖

46. 3rd. The danger resulting from a deficient supply of water, being produced by the undue heating of parts of a boiler, many means have been proposed for showing such an increase of temperature, before it attains a dangerous degree. The fusible plates applied to the top of the boiler may be intended to indicate the general temperature of the steam when saturated with moisture or not, or the local temperature resulting from the rising of hot and unsaturated steam, produced by unduly heated metal.

* The hydrostat described in No. XXX. of replies is inadmissible, from the interior of the boiler being occupied by a second cylinder leaving only an annular space for the production of steam. For the alarm floats of J. L. Sullivan, Esq., see Silliman's Journal, vol. xx. p. 1.

† See the alarm float of Siebe. Lond. Journ. Arts. vol. xiii. p. 273. The first of those known to the Committee.

‡ Report p. p. 14. 15. Plate 4. Fig. A. Journ. Frank. Inst. vol. xvii. pp. 13, 14.

§ It is exposed to a slight objection from steam pressure acting to keep the disks upon the openings, these latter are, however, quite small, and the pressing surfaces of the disks may be regulated accordingly.

The float described by Mr. Ewbank, Jour. Frank. Inst. vol. x. p. 7, is also referred to by the Committee as deserving a full trial.

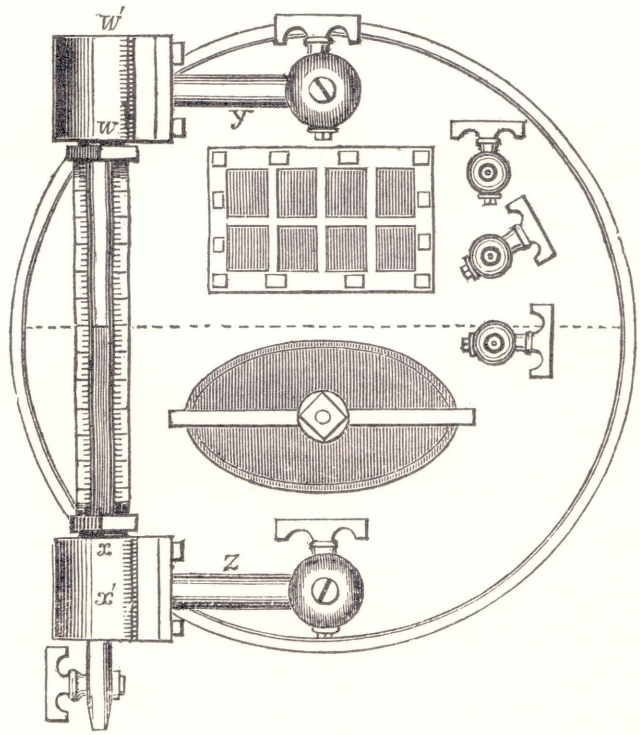
‖ The following description of the tube water gauge used by the Committee is taken from the first part of their report, p. 12, &c. (Jour. Frank. Inst. vol. xvii. p. 10).

"The tube gauge is shown in the annexed figure. *w x* is a tube of green glass

In any case they will be exposed to pressure; though to less in the second case than in the first. The objections already urged, and derived from experiment, will apply to their use, in the ordinary way, in any one of these cases. Indeed without this objection, it appears that as the source of danger is the heated metal, to this the indicator of temperature should be applied.

47. Various methods of indicating the temperature of a part or parts of a boiler have been contrived. One of the most simple is to apply the common thermometer, inserting the bulb and as much of the stem as is necessary, in a tube closed at one end and fastened into the boiler. The tube should contain mercury, through which the heat is conducted to the thermometer. Such a tube may be placed at or near the water line of a boiler, at the fire end of a flue, or in general at the place of greatest exposure to heat from a deficiency of water, of which there will usually be one or more well determined, according to the form of the boiler. A mark upon the scale of the thermometer will show the temperature above which the metal must not be allowed to rise, either from an increased elastic force in the steam, or from a deficient supply of water. The fragility of the

passing into the stuffing boxes, w' x'; the stuffing enables an adjustment to be made for the unequal expansion of the glass and metal by heat, and prevents fracture on the subsequent cooling of the apparatus. y and z, are pipes connecting the tube with the boiler; these have conical terminations, by which the pipes are readily attached to, and detached



from, the tubes connecting them with the boiler, which are provided with stop-cocks: coupling screws might, in practice, be substituted for these conical terminations. To protect the tube, w x, from currents of air, it was surrounded by a second tube, loosely applied. A scale was attached to w x, to indicate the level of the water within the boiler.

instrument, its inconvenient length, or position in certain cases, and its not acting as an alarm, are the principal objections to its use.*

48. The expanding rods proposed by Mr. Cadwallader Evans are ingenious; they give, however, not the local temperature of the boiler, but its general temperature, along the lines to which the rods are applied. A much more appropriate device, is the application of fusible metal proposed by the same gentleman.† This is intended to take the place of the ordinary fusible plate, and to avoid the difficulty, originally existing, but since remedied‡, of replacing the plate when it had fused. In the apparatus submitted to the Committee§ by their chairman, and subsequently made the object of experiment, the fusible metal is applied to the most exposed part of a boiler: it is so small in quantity, that it will serve to indicate a local temperature, while the motion which indicates its fusion is independent of the quantity of the fusible metal. These instruments are intended, respectively, to give notice when the steam or the metal of the boiler is exposed to a temperature, much below that which would produce danger. Both of them, after giving an alarm, can be immediately restored to action if the temperature within has been made to decrease.‖

* For a detailed description of the mode of applying the thermometer see the report of Com. on Expl. Part. I. pages 7 and 8, and Jour. Frank. Inst. vol. xvii. pp. 5, 6.

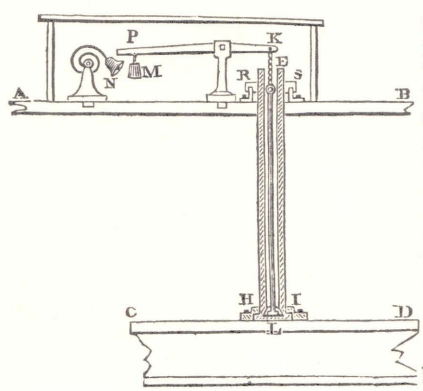
† Communication to Com. on Explosion, No. XXII. of Replies &c. Jour. Frank. Inst. vol. ix. February 1832. Patented in May 1834. See Specification in Jour. Frank. Inst. vol. xiv. p. 391. The Committee prefer this to the apparatus acting by the expansion of mercury.

‡ Hall's method of applying the fusible plate. Bulletin de la Soc. d'Encouragement, &c.

§ Described in Jour. Frank. Inst. vol. x. p. 217.

‖ The apparatus devised by the Chairman of this Committee, was made the subject of experiments, and, with them, is thus described in Part I. of the Report of Com. on Expl. It is obviously as applicable to a common boiler, as to one with interior flues.

"A tube of iron, or copper," according to the material of the boiler, "closed at the lower end, passes through the top of the boiler, its closed end reaching the flue to which it is attached." "This tube, it will be observed, affords a ready access to the flue, to ascertain its temperature, without any restraint from packing." "A mass of fusible metal placed at the bottom of the tube," "will become fluid very nearly as soon as the flue takes the temperature of fusion of the alloy." "To show when the metal at the bottom of the tube becomes fluid, a stem is attached with a cord and weight," "or with a lever and weight." "The weight and longer arm of the lever, descending, may be made to ring a bell, or, by appropriate attachments, to turn a cock, permitting just enough steam to issue to give the alarm, and then to be closed at once. A projection on the lower end of the rod prevents it from being drawn from the metal until this latter is fused, and by widening the lower part of the tube, making it slightly tapering, the metal is kept from being drawn out by the rod."



In the annexed figure "AB is a section through the top of the boiler; CD, a corresponding section of its flue, EH represents a tube closed at the lower end, which is attached to the upper side of the flue. The mode of attachment by a projection on the tube and a ring screwed to the flue, is shown in the figure, as also the stuffing-box, RS, through which the upper end of the tube passes. The lower part HI, of the tube, is made tapering, to retain the fusible metal. KL is the stem, the lower part being inclosed by the fusible metal, the upper part attached by a chain to a lever KP. The weight M, draws the rod KL upwards, and on the fusion of the alloy HI, carries the lever below the bell N, which, being attached to a spring, rings an alarm."

By very simple changes in the apparatus, the fusible metal might be applied to the boilers of locomotive engines.

49. *Second.—The undue heating of parts of a boiler may be produced by deposites.*

No cause of undue heating is better made out, than this one, and the remedy is of the most simple kind.

The water of all rivers contains, in suspension, in greater or less quantities, the muddy particles detached from their banks or beds, and may contain in solution, salts derived from the same sources, or from the springs which supply the stream. The water of springs generally contains so large

The form of this apparatus, which was subjected to trial by the Committee, was essentially the same with that described. One of the tubes in which the thermometers were ordinarily placed, was used to contain the fusible metal, and as giving the more severe test, the short one entering only into the steam, was selected. For the convenience of removing the metal, it was placed in a metallic case, fitting loosely into the iron tube, and having a wire attached, by which it could be drawn out of the tube. This certainly diminished the sensibility of the apparatus, particularly, as the case was quite as thick as the inclosing tube, and as there was a small space between its convex surface and that of the tube; it was required, however, for the convenience of the experiments.

The results of the several trials are contained in the following table. The temperature was registered by the adjoining thermometer dipping into the water of the boiler, and already often referred to; it was raised as rapidly as possible in all the experiments except the first. The first four trials were made on an occasion specially devoted to this purpose, the last two were made incidentally when upon another subject.

Number of trial.	Temperature. Fah°.	Remarks.
1	268	Stem rises. No particular attention paid to raising the temperature rapidly.
2	270	Stem rises. Steam raised rapidly.
3		Metal drawn out and suffered to cool, re-deposited cold in tube. Steam at 258°, and raised to 274° in 2½ minutes.
	274	Stem rises.
4		Metal drawn out and cooled. Steam at 250°, when metal was replaced. Steam raised to 274° in 3 minutes.
	274	Stem rises.
	252	Metal had not become solid again. Steam let off rapidly.
5	270	Melted below this temperature.
6	256	Stem rises. Metal remains a soft solid, so that the stem can be drawn out, until 240°.

A fact noticed during the experiments on fusible alloys was again verified in these; namely, that the mixtures of metals require a considerable time to change their state of solidity or of fluidity, so that in the former case they may be raised, if heated rapidly above the true temperature of fluidity, and in the latter case they may be cooled much below this temperature, without solidifying. The alloy used in these experiments, appears to have put the apparatus very fully upon its trial in his respect, and the experiments were performed so rapidly as to give a further severe test. On the occasion devoted to the trials when the steam was not urged up with its greatest rapidity, the stem was drawn out at 268° when more rapidly at 270°, and with the fire at its maximum intensity, when the water was raised in temperature 24° in three minutes, the stem was drawn out at 274°. In other experiments it gave way at 256°. The range is 18° Fah., corresponding at ten atmospheres, to less than two atmospheres, under the test of very severe comparisons. There appears no reason to doubt, that when tested by no more rigid modes than practice would furnish, this apparatus would not only apply as an alarm to prevent undue heating of the parts of the boiler, but as a manageable, and useful check, in ordinary cases, upon the safety-valve Report &c., Part I. and Jour. Frank. Inst. vol. xvii. p. 85.

an impregnation of saline matter, as to decompose soap. The rivers of our Atlantic States, where perfectly fresh, contain few dissolved impurities, while many of those of the Western States are highly charged with calcareous matter. When waters holding substances in suspension or solution, are evaporated, a sediment is deposited, varying in nature with the water employed. As the quantity of solid matter contained in the water varies, so the time required for such a deposite to take place, from the feeding water of a steam-boiler, must be very variable. If a deposite is allowed to remain in a boiler, it gradually increases in thickness and in density; the heat which before passed rapidly from the metal to the water, is now impeded by a mass of viscid or of solid matter, which is a bad circulator or conductor of heat, and the temperature of the metal rises. The sediment thus heated increases in denseness, and may even form a hard crust upon the bottom of the boiler. A complete non-conducting coat is thus formed, which if from its nature liable to crack or fissure, may allow water to have access to the heated metal below, and produce an explosion. This supposition is, however, as will be seen by no means necessary to such a result. The most usual action of the sediment would seem to be as follows. When it has accumulated in thickness, sufficiently to produce a temperature in the metal, at which its strength is inadequate to bear the pressure without extending, it yields, and becoming more and more attenuated, finally bursts. It seems that the first yielding may bring water in contact with the metal so as to cool it, when the steam produced is not sufficient materially to increase the pressure within the boiler. Thus the attenuation may increase for a considerable time and gradually, and at last the bursting not produce any more injurious effect than to stop the working of the engine.

Accidental circumstances of figure, heat &c., seem frequently to determine the places of deposite of these masses of sediment, but it is principally observed at the fire-end of the boiler, where its presence is most dangerous.

50. The Committee have derived much information of a practical kind on this subject, and coming as it does from entirely different quarters of the country, where the water depositing the sediment was of different qualities, the details agree very remarkably.

Col. S. H. Long* describes a deposite found in one of the boilers of the Western Engineer, a boat used in the exploring expedition of 1818. The sediment had collected in less than two days so as to be two inches thick, and was found in parts of the boiler, where from its construction, the heat was greatest. A difficulty in making steam enough for the supply of the engine, was observed, and induced an examination of the boilers, in one of which, the metal at a particular spot was found to have been made to project an inch and a half. In this case timely precaution prevented further evil consequences.

51. The plan of "blowing off" the lower parts of the fluid in a boiler, which is very generally used in turbid streams to the West, is, no doubt, of considerable service while the boat is running, but should never be used as a substitute for cleaning the boilers, when opportunity is afforded for this complete operation. Indeed it must be carefully executed, since if the flues are bared by it, any deposite upon them may become hardened before the boiler is replenished with water.

52. A practical Engineer of New Albany, Indiana, Mr. Benton,† states

* Replies to Circular of Com. on Expl. No. II.

† Reply to Circular of Com. on. Expl., by Erasmus W. Benton, No. VIII.

that he has found deposites in boilers, used on our Western waters, "almost as hard as the iron itself." These consist of a mixture of calcareous matter with the ordinary mud of the rivers.

The very consistent and satisfactory accounts given of the explosion of a boiler of the steamboat Caledonia, on the Mississippi, show that the disaster had its origin, at least in part, in the deposite within the boiler. The boat had eight connected cylinder boilers of wrought iron, for high steam, thirty inches in diameter and twenty feet long, with interior flues. The engine had been in operation for seven consecutive days, prior to the accident, and had, just before its occurrence, been stopped for about eight hours, to repair the machinery. During the time of stopping, the boilers were not blown out, and two hours after resuming the working of the engine the explosion occurred. On subsequent examination, it was found to have occurred in a patch, which had been put on the year before with *copper* rivets; the sediment on the bottom of the boiler was found to have been heated, so as to render it very hard. The rent began at about one third of the diameter of the boiler from the bottom, that is, at or near the fire line, and passed upwards. The sediment had caused the heating of the copper rivets, and, it is probable, that the working pressure of the steam accomplished the rest.

53. The effect of a deposite of a different kind, in a boiler, near Richmond, Virginia, is well described by Mr. Burr.* The boiler was of wrought iron, five-sixteenths of an inch thick; the water used for its supply was a chalybeate, but not so strong as to prevent its common use, as a beverage, by the workmen. A few weeks after the engine had been put in operation, a crack was observed in the boiler, just over the fire, and on examination, a deposite of oxide of iron was found in this place. The fire-end is stated to have been lowest in the setting of the boiler. A plate of wrought iron was substituted for that which had cracked. In four or five weeks a swelling began to form upon this plate, which continued to increase until it attained a considerable size, and in ten days from the first on which the protuberance had been observed, the boiler burst. No great damage was done. The iron was found to have been diminished in thickness, at the spot where the rent occurred, to one-eighth of an inch.

54. The deposites in boilers using salt water are no less dangerous. Mr. Lester† gives an account of the case of the boilers in the steamboat Eagle, of Boston, which leaked after being in use two or three weeks, and on examination were found to contain a deposite of from two to three inches thick, and which, in some parts, was so hard as to require the use of a hammer and chisel to remove it.‡

55. Various other cases are on record of the effects of deposites in boilers, but the characteristic ones which have been selected convey all the information necessary. They show that no rule as to the time of cleansing a boiler can be general, and fully enforce the necessity for care upon this point. Farinaceous substances introduced into a boiler may tend to ren-

* Jour. Frank. Inst., vol. vi. p. 334.

† Letter to Sec. Treas. U. S. Replies to Com. on Expl., No. XVII. See also Jour. Frank. Inst., vol. vii. p. 289, &c.

‡ In a letter to the editor of the Jour. Frank. Inst., a gentleman of Boston, states that in a boiler using salt water, a deposite of more than two inches in thickness occurred in less than twenty days. Mr. West states that deposites, chiefly of sulphate of lime, occur in from one to six weeks of use, in the boilers at Manchester. See Jour. Royal Institution, vol. i. p. 42. See also F. Naested's letter to Sec. Treas. U. S., Doc. H. Rep. U.S., 1832–3, No. 478, p. 52.

der frequent cleansing less necessary in cases of sedimentary matter, but cannot dispense with it.* Sound economy, as well as safety, require frequent cleansing of a boiler using hard or muddy water. The least that can happen, after the accumulation of sediment, is the injury of the boiler, perhaps its bursting, and a true explosion may result. Two violent explosions, at Bowen's mill,† and at McMickle's mill in Pittsburgh, are fairly attributable to the effect of sediment, and there does not appear in either case to have been a deficiency of water at the time of the explosion.

56. The accidental introduction of materials which are bad conductors of heat within a boiler may produce the same effect as the deposites just described. Mr. Benton‡ suggests that loose packing from the steam cylinder is sometimes passed through the force-pump and collecting under the flues, causes them to be highly heated. M. Arago mentions an instance of a rent made in a boiler, at Paris,§ by the accidental resting of a rag on the bottom of the boiler.

57. Frequent cleansing of the boiler or blowing out the lowest portions by small quantities at a time, are the true preventives to accidents from deposites. Besides them, however, the use of chemical reagents has been proposed for limestone water, and filtering in the case of muddy water. The former of these would prove but a partial remedy, and in unskilful hands would be dangerous, and the latter would probably be objected to on the score of its considerable expense. When the escape steam is allowed to run to waste this would be especially the case.

58. It has been also proposed to use boxes for collecting the sediment, but from them the committee would not anticipate any very good result, though they might in part facilitate the cleansing of a boiler.

59. *Third.—The careening of a steamboat may expose parts of the boiler to heat without their being covered by water, and a subsequent return to its level will bring water in contact with the heated metal.*

There is no evidence known to the Committee that the careening of a boat has ever produced accident in any other than the small connected cylinder boilers, so extensively used in the boats navigating the Western waters. In these, the danger has been forcibly pointed out by several correspondents,‖ and means of remedying it suggested.¶ These boilers communicate by pipes below the ordinary water level, and are supplied by the same forcing-pump. The fire is most generally applied to the exterior of

* It was stated on the authority of Sig. Ferrari, that coarse charcoal prevents or removes deposites in boilers. (Jour. Frank. Inst. vol. ix. p. 420.) The Society of Arts of London awarded in 1833, a premium to Mr. Jas. Bedford for rendering deposites readily removeable by introducing sperm oil into the boiler. We are not aware to what extent this device has been tried. (Trans. Soc. Arts. vol. xlix. Part II. p. 88.) The use of grease for the same purpose is recommended in the Lond. Mechs. Mag. vol. vi. p. 308. and in the same journal (Vol. ii, p. 206.) it is stated that the radicles of barley produced in the process of malting prevent deposites. These act on the same principle as the fecula of potatoes. They merely retard the formation of a deposite, and by rendering the fluid viscid, no doubt ultimately affect the generation of steam.

† Replies to Circular, &c. No. XII. Letter of Thos. W. Bakewell, Esq. to Sec. Treas. U. S,

‡ Replies, &c. No. VIII.

§ Used in producing steam to heat the exchange.

‖ The first communication made to the Committee on this subject was by James J. Rush, Esq. of the firm of Rush and Muhlenberg; by some accident the drawings presented by him were not deposited among the papers of the Committee, and a similar diagram to that of Mr. Rush being afterwards presented by Mr. C. Evans was published among the replies to the Circular of the Com., No. XXII.

¶ Replies to Circular, &c. No. XXII. Earle on Explosions, Journ. Frank. Inst. vol. vii. p. 154.

the boilers, and they have besides interior flues. Being placed side by side, the length of the boiler being parallel to the keel of the boat, they occupy according to their size and number a more or less considerable portion of its breadth. The six contiguous boilers of the steamboat Helen McGregor, and the eight of the Caledonia occupied certainly not less than twenty two feet in breadth of the boat. Calculating upon the dimensions of the boilers in the first named boat, and taking into view the circumstances under which the water has access to the heated metal, we find that a depression of nine inches, at the extreme boiler, taking place about the axis of the set of boilers, would expose a surface of boiler and flue together competent to supply, when the water returned upon them, one-third more steam than the ordinary working of the boiler could furnish: this supply being kept up, at an average, during the cooling of the elevated boilers to their ordinary working temperature. This danger might easily be met by an increased area of safety-valve if indeed those commonly used would be insufficient, for the escape of the extra steam.* But the danger from even the working pressure acting upon the metal of which the tenacity has been much decreased, is the real source of danger, and is not thus to be parried. There are but about 440 degrees of Fahrenheit's scale between the working pressure of eleven atmospheres, and a red heat visible in the dark.

This careening of the boat is liable to occur at every landing-place and to last for a considerable time. Whenever a passing boat, an engaging view, or accident shall call the passengers to one side of the boat, it will be thrown out of trim.

60. In the small boats on our Atlantic rivers there are heavy carriages used to keep the deck level; these are also used in the English steam-packets which carry sails, but the Committee are not aware that they are employed in the boats of our Western waters.

61. *Different modes of remedying the evil under discussion, and to be applied to the boilers themselves have been suggested.*

The first of these which came before the Committee, and which we believe has been applied in practice, was by Mr. James J. Rush. Doors are placed in the flues, at a point furthest from the fire-end, which, when opened, check the draught through the furnace and flues, and consequently prevent their becoming unduly heated. These are to be thrown open at each landing-place. They do not, however, meet the case of accidental careening of the boat, unless made self-acting by expanding rods, as was proposed by Mr. Rush. They expose the flues to the action of air containing its full supply of oxygen, and must tend therefore to oxidize them more rapidly than in the ordinary wear of the engine.

62. The other devices before the Committee are those of Mr. C. Evans,† and of Mr. J. S. Williams.‡ The first places the mouth of the feeding-pipe just below the proper level of the water in the boiler, so that it shall be laid bare by a change of level, and the water be prevented from escaping from the higher boilers. This would remedy the evil except in cases where the careening was sufficiently long continued to exhaust the upper boilers of water by the ordinary working of the engine; those boilers

* We are not able to make the calculation corresponding to this remark, not having the dimensions of the safety-valve, or valves, of the boilers of any one of the Western boats.

† Replies to Circular, &c. No. XXII.

‡ Jour. Frank. Inst. vol. viii. p. 289. The method adopted by Mr. W. C. Redfield places the means of feeding separately, or in the connected way, within the control of the engineer. This was not presented to the Committee, but may be found alluded to in the Documents of the House of Representatives of the United States, 1832-3, No. 478, p. 17.

of which the supply pipes are bare not being likely to receive any supply from the pump. Mr. Williams places the supply pipes below the boilers and feeds through valves opening upwards, which of course prevent any return of water. The valves in this machine and also those proposed by Mr. Evans to prevent any escape of water from the higher boilers, would be objectionable. The method of cleansing the pipes proposed by Mr. Evans is very ingenious.

63. After a careful examination of these devices the Committee are of opinion that they present but partial remedies for the evils which they are intended to meet, and they consider that nothing less than detaching these boilers from each other, and feeding them singly, or at most in pairs, will prove effectual. They would therefore respectfully, but earnestly, urge this upon constructors and owners.

64. *Fourth. Are there cases in which the metal of a boiler may become unduly heated when in contact with water?*

After much reflection and examination the Committee are of opinion that such cases *may* occur. They believe that such have occurred, though not frequently, and that with the common thicknesses of iron and copper boilers, and modes of arranging the furnaces, there is very little liability of their occurrence. Still it is well to recognise that such may be the case, as it may prevent accident by watchfulness in the use of a new construction of boiler, or application of the fire.

65. Mr. F. Graff* mentions specially an instance " in which the heads of the bolts burning off over the fire-place, and the joints parting;" " the boiling water passed into the ash pit." From his known carefulness, there is no reason to suspect that there was sediment in this boiler, which was one of the low-pressure boilers used at the Philadelphia water-works.

66. Mr. Hebert† gives two cases, in the first three different rents of an iron boiler occurred at the same spot, at different times. Previous to the first " disruption, there was observed a bulging, or swelling out, of the metal, which gradually increased until it became nearly of a hemispherical figure, when it burst open and let the water out of the boiler into the fire. The boiler was repaired by putting a thick patch of malleable plate iron over the hole, when after about six weeks wear and exposure to the fire, this metal bulged out again, and burst asunder; a third patch was substituted, and in about a similar period of time was destroyed in like manner." " The cause of these ruptures appeared upon investigation to be owing to a partial and very intense heat impinging against that particular spot where they took place." If to this detail had been added proofs that the first rupture was not caused by sediment, nor by a defect in the metal, the evidence would have been complete. It is not however probable that either of these causes were actually operative, since the second and third plates are stated to have bulged out, in the manner of the first, and if sediment had collected at this spot, it could not thrice have escaped notice. The defect in malleable iron, to which the Committee alluded above, is the the want of connection in parts of a plate, resulting from imperfect welding before rolling, and which sometimes separates the plates into distinct layers, for a considerable extent.

In the communication just referred to, Mr. Hebert further states, that the destruction of a boiler, occurring twice in the same place, was traced by Mr. John Martineau, a respectable engineer of London, to the impinging of a current of air upon this spot.

* Letter to Councils. Replies to Circular, &c., 4th of No. I.
† Replies, &c. No. XI.

67. A case apparently of the kind now under discussion, but which was found, subsequently, to be due to the imperfect union of the parts of a sheet of metal of the boiler is as follows. Part of a boiler belonging to Messrs. Merrick and Agnew, of this city, was observed to be protruded, in a similar way to that described by Mr. Hebert. Suspecting the presence of sediment, the boiler was examined and found to be clean. It was a cylindrical boiler, of wrought iron, the fire applied on the exterior and at one end, and without interior flues. The fuel was anthracite coal. The effect was next attributed to the intense local heat produced by this fuel, and the grate bars being lowered the swelling made no further progress. It has been since ascertained that there was a separation into laminæ of the iron, at this place, requiring the removal of part of the sheet.

68. While, then, the evidence in the cases preceding the last is certainly incomplete, the Committee conceive that they are leaning towards the side of safety by admitting the possibility of the occurrence of danger, to the engineer and fireman at least, from peculiarities in the arrangement of a boiler or of the fire which heats it.

69. In these remarks it has been supposed that there is a considerable column of water over the metal; if that should not be the case it may well happen that the steam-bubbles will form so numerously on or near the iron as to allow it, while they rest there, to become heated above what it would be, if the water were in absolute contact with the metal.* This will especially occur with a viscid fluid, such as salt water, or water with much sediment suspended.

70. The views suggested by the several sections of the preceding head are the following:

1. The feeding of a steamboat boiler should not be done at intervals, but go on throughout the working of the engine.

When the engine is stopped, as at a landing, or to take up passengers, &c., the water should still be supplied by the engine itself, or by a subsidiary one, or by hand. In this case the free safety-valve should be raised. The practice of wasting water by opening a valve, when the forcing-pump is not in action, is considered dangerous.

2. If the water should by any accident get down so as to expose a flue or flues, the fire should be in part extinguished, to cool the boiler before adding water. If the engine is at rest, in such a case, it should not be put in motion. If it is in motion it should be slackened, or stopped, the furnace-doors opened, and the heat got down. Then water may be thrown in. The opening of a safety-valve should in such a case be avoided. The engineer should remember that as life is at stake, he cannot be too prudent.

Such a condition of things, however, ought never to be allowed to occur, and the responsibility for the danger which results, must rest upon the master, the engineer, and his assistants.

3. If a self-regulating apparatus for the supply of water is used it should be closely watched, and on no account be implicitly trusted to. It may be a convenience, but can, in no case, be a substitute for human care.

4. For ascertaining the level of the water within a boiler, the Committee recommend the glass tube water-gauge, a form of which is shown in the foregoing pages (p. 24).

5. The Committee recommend for every boiler a fusible metal apparatus,

* Replies, &c., No. II. Communication of "an Engineer." Philos. Mag. vol. i. p. 403.

the metal of which shall be inclosed in a tube, so as not to expose it to pressure.

In boilers without flues it should be attached at the water-line; in those with flues, at the highest part of the flues; or if level, at the part likely to be most rapidly heated, as at the juncture of several flues into one, a sudden change of direction, or the place of most active combustion of the fire.

The form described in the report (p. 25,) is convenient, and the lever should act upon a bell, and upon a small cock. The apparatus should be inclosed, the master of the steamboat having the key of the inclosure, which should further be so arranged as to protect the apparatus from the weather.

The quantity of metal should be no greater than is required to keep the rod in its place. The metal should be regulated so as to melt at a temperature of fifteen degrees* above that corresponding to the working pressure. Tables for this purpose, will be found annexed.

If the metal is melted, the injection of water, or the opening of the furnace-doors, will reduce the temperature of the heated parts; or lower the pressure of the steam if that should have been too high, and the safety-valves be out of order.

By sounding with the rod, it will be ascertained when the metal is about to recongeal, as it becomes a soft solid into which the rod may be forced. If, accidentally, the metal congeals without taking in the rod, the end of the latter being heated, will melt the fusible alloy.

If the safety-valves do their duty, this metal will never be melted by increase of temperature, caused by an increase in the elastic force of the steam.

6. The true remedy for undue heating of boilers by deposites is frequently cleansing them. When this is impracticable, blowing out should be cautiously resorted to, so as not to lay bare the flues of water. The danger from these deposites is especially great in salt water, and muddy water mixed with calcareous matters. It should be guarded against by ascertaining the time required for the water used, to make a sensible deposite. No general rule in regard to this can be given, since boilers in different places and even those fed by springs at short distances apart are liable to deposites in different times.

Negligence on this point will always produce the rapid destruction of a boiler, and may cause it to burst, or even to explode.

No substitute for the care just recommended, has yet been found.

7. The following table of fusible alloys applicable to boilers working at pressures from one to thirteen atmospheres, is deduced from the experiments of the Committee.† The alloys are those, determined approximately, which at temperatures severally 15° Fah. above the working temperatures will allow a metallic stem to be drawn out from the mass. The principles which guided the Committee in their experiments may be seen by referring to Part I. of their Report. (p. 36, &c.) The proportions are given in parts by weight.

* This difference of temperature corresponds at a pressure of two atmospheres, to half an atmosphere or one-half the bursting pressure, and at eleven atmospheres to rather more than two atmospheres, or one-fifth of the bursting pressure. The difference is not, however, too great at low-pressures, because an excess of strength may rather be expected in the low-pressure boilers as now made, and the alloys, containing bismuth, pass through the different states from solidity to liquidity, by slow degrees.

† Report of Com. on Explosions, Part I. p. 36. Journ. Frank. Inst. vol. xvii. p. 86.

TABLE OF ALLOYS FOR USE IN CLOSED TUBES, AND WITH A METALLIC STEM.

Working pressure in atmospheres.	Tin.	Lead.	Bismuth.	Working pressure in atmospheres.	Tin.	Lead.	Bismuth.	Working pressure in atmospheres.	Tin.	Lead.	Working pressure in atmospheres.	Tin.	Lead.
1½	8	8	7.5	4	8	8	3.4	8	8	8	12	8	12.3
2	8	8	6.2	5	8	8	2.2	9	8	9.8	13	8	13.2
2½	8	8	5.3	6	8	8	1.2	10	8	10.6			
3	8	8	4.6	7	8	8	0.5	11	8	11.4			

71.—III. *Explosions may arise from defects in the construction of a boiler, or its appendages.*

This comprehensive division includes the discussion of the form, material and mode of manufacture of the boiler and of its appendages. The Committee have, however, no desire to interfere with the present or future state of the engine in these respects, further than as their duty requires them to give candidly to the public, their opinion of facts which are on record.

72. 1*st.*—*Form.* The influence of the form of a boiler in producing danger is of course very great; but to consider the numerous varieties of form would be impossible, even if their minute differences were known to the Committee. Every boiler should be required to stand frequent proofs as a test of its sufficient strength, but the working properties of each, with originally adequate strength, may be very different.

73. It may, in general, be remarked, that the old wagon-boiler of Watt, should be only used when very low steam is employed. The varieties of the cylinder-boiler, with or without interior flues, are in most common use in the steamboat-engines of this country. Of these, experience, both abroad and at home, has shown those without flues to be the more safe, and those with them the more economical. The heads of these boilers are, in this country, plane surfaces, in England, frequently, hemispherical, and in France, are required by law, to be of the latter named figure. There is no reason, however, to doubt the sufficiency of strength of the thick plane wrought-iron heads. Of the flues used, those in the smaller cylinders, which pass directly through both heads of the boiler are the more safe ;* the flues passing through the convex surface, called L flues, and those which in the larger boilers return without passing through both heads, add nothing to the strength of the cylinders. Observation has shown that boilers with interior furnaces, or flues, commonly give way by the yielding of the flues, or by blowing off the heads. The tubular boilers of Woolf, have, but in one case, as far as the knowledge of the Committee extends,† been used in this country. Other forms of tubular boilers, in which very small tubes contain the water to be vaporized, have, in no case, to their knowledge, on full trial, been found successful. The case is very different

* Experience seems to warrant this conclusion, and it does not appear probable that the difference of temperature between the flue and outer shell, even in boilers with interior furnaces, can be sufficient to injure a wrought-iron head, by the excess of the expansion of the flue. The case is different when cast-iron is used for a boiler-head.

† At Richmond, Virginia. See Burr on Explosions. Journ. Frank. Inst. vol. vi. p. 334.

when, as in the locomotive boilers, the tubes are used as flues: and for obvious reasons. Such boilers have, however, only lately been applied to steamboats.

There does not seem to the Committee, evidence to show that any of these forms are essentially dangerous, though, as before remarked, there are grades among them as to impunity from careless management. From this remark, however, in some degree, should be excepted the L flue-boiler, which is incident always to a source of danger, hereafter to be pointed out. The remarks apply to single, or detached boilers.

74. Connected boilers, on board of steamboats, are incident to a source of danger which has already been pointed out, (art. 59, &c.) and after examining the remedies which have been proposed to meet these circumstances, the Committee are of opinion that they are of so varied a kind that the use of these boilers cannot be continued without certain danger, and therefore ought to be laid aside. Those at present in use could easily be detached, so as to connect only two boilers at most, and have a separate supply-pump for each pair.

75. In a former division of the subject, (II.) the Committee showed the great danger which is produced in a boiler by highly heated metal; any boiler, therefore, which has parts exposed to heat, without being in contact with water, is essentially defective. The L flue-boiler is of this kind, though as it is only used in small cylinders, the exposure is not considerable.* The boiler with a steam-chimney presents an extension of this exposure, the boiler being continued up vertically at one end, so as to inclose the flue.† The idea is to economise the heat found in this flue, by heating the steam which is around it, and thus producing a small surcharge of heat which prevents condensation in the steam-pipe and cylinder. But the flues which the chimneys inclose, are thus exposed to become unduly heated Two explosions which have occurred in boilers with steam-chimneys‡ have torn the same portion of the flue, and were so

* A curious case of the overheating of a flue by the accumulation, and subsequent taking fire of soot, is described by Mr. Hebert in No. XI. of the Replies to the Circular of Committee on Explosions.

† It should be recorded to the credit of the liberal minded patentee of this boiler, that he has afforded every opportunity to investigate its defects, and appears no sooner to have been convinced of the danger to particular parts of it, than he has applied his skill to produce a remedy.

‡ In justice to the force of this conclusion, the Committee feel it necessary to give extracts from the excellent accounts of the explosions on board of the Ohio and of the William Gibbons steamboats, by Thos. Ewbank, Esq., of New York. The first of these explosions, occurred on the Hudson, in 1832, and the second, in New York harbour, in 1836. The annexed figures represent in plan and section the ruptured flue of the Ohio. WW, in the elevation, is the water line, C the flue around which the steam chimney is placed, and S the steam-pipe leading from the steam-chimney. The rent took place from fifteen to twenty inches above the water line. This part of the flue is always exposed to the heated air from the horizontal flues which unite in the flue E, and is never covered by water. The line of fracture does not deviate more than six inches from a horizontal line. It is partly along a line of rivets, but chiefly through the centre of the sheets. In portions of one sheet, the metal is reduced from its original thickness of one-quarter of an inch, to one-eighth, and even to one-sixteenth of an inch. Jour. Frank. Inst., vol. x. p. 226, No. XXIX. Replies to Circular, &c. The

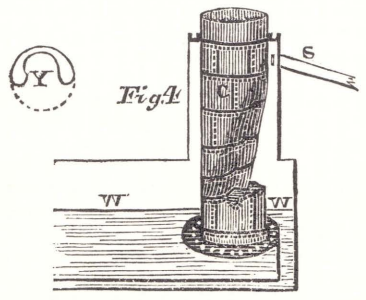


Fig 1

similar, as to show that they are to be attributed to an inherent defect in this construction. Indeed the presence of metal through which a highly heated draught is passing, while it is in contact only with steam, which cannot carry off the heat rapidly, is sufficient to warrant a decision against such a form of boiler, even if facts had not spoken so loudly in regard to it.

76. The Committee feel constrained to recommend to constructors to discontinue the making of connected boilers, of those with L flues, and with the extension constituting a steam-chimney.

77. It would be improper to leave this part of our subject, without calling attention to another point in the construction of boilers, which is to be avoided. It is the formation of small spaces intended to contain water and surrounded by fire.* All experience has shown that steam cannot be generated in small tubes without driving out the water, and these arrangements are equivalent to tubes; and besides being liable to the accumulation of deposites, they are exposed to have the water carried from them unless when under considerable pressure. The weakness of boilers of these irregular forms should never be lost sight of.

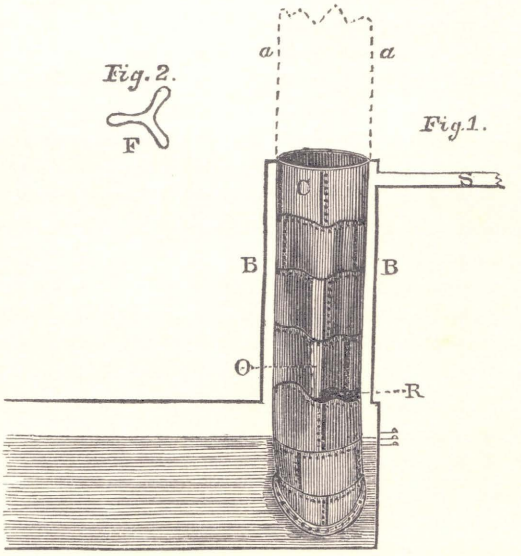
78. *2nd.—Material and manufacture.* As early as 1818 a Committee of the British House of Commons, on the authority of practical and scientific men whom they examined, recommended the disuse of cast-iron as a material for steam-boilers. This material has now so generally been abandoned, for this purpose, that remarks upon its defects are not necessary. Even the cast-iron heads for boilers which were used a few years since on the Mississippi are, the Committee believe, now giving place to wrought-iron ones. The materials in common use for steam boilers are wrought-iron and copper.

79. The committee have made, by the arrangement stated in the preface to the first part of their report, an extensive series of experiments on the strength of the different varieties of wrought-iron and copper, manufactured for steam boilers, in the United States. These experiments they

William Gibbons has one boiler of wrought iron, and similar in construction to those of "The Ohio" and "New England," but having a greater number of horizontal flues. The flue BB within the steam-chimney, was collapsed so as to form a three cusped figure, as shown in fig. 2. The rent R, thus produced, was four inches above the roof of the boiler. It was in one of the horizontal seams, and confined almost wholly to it, extending nearly three feet, or about one-third of the circumference of the flue. The flue was iron, one-fourth of an inch in thickness, and its thickness was not sensibly diminished previous to rupture. Jour. Frank. Inst. vol. xvii. p. 298. The fuel used ordinarily, was a mixture of anthracite coal and wood, but, on this occasion, it appears that the fire had been urged with quantities of wood.

Fig. 2.

Fig. 1.



* Ewbank on the explosion of the boilers of the steamboat New England. Jour. Frank. Inst., vol. xiii. pp. 292, 293.

hoped to have presented before making this report, but circumstances not now necessary to be made public have prevented them from doing so, and they deem it inexpedient longer to delay on this account. They must refer, therefore, to a report, specially upon this subject, for a complete development of their views, as well as for information in regard to the proper thicknesses for steam boilers, working under different pressures. They ought, however, to remark here, that the views usually entertained of the importance of working iron, have been entirely confirmed by them. The ultimate strength of a bar, or sheet of iron coinciding more nearly with the strength which the whole bar exerts to prevent a first fracture, or the bar or sheet being rendered more uniformly strong, and therefore better adapted for use in the construction of steam-boilers, the more it is worked. Iron which has been heated nearly to redness has its tenacity permanently injured, being affected, though in a less degree than copper, the weakness of which in such a case has long been well established.*

80. There can be no doubt that the strength of boilers may be diminished by constant and often unequal pressure, by which the material is injured so far as to give way under a less strain, than that which it may once have borne.† By ordinary wear, from oxidation, &c. their strength is necessarily much impaired.

81. When salt water, or spring water highly charged with saline matter, is used to feed boilers, iron is very rapidly acted on, and extreme care should be used in frequently cleansing them.‡ Careful owners would resort to more frequent proof by the forcing pump than in other cases. This would serve to detect corrosion in particular spots, to which the material is so liable. Copper boilers not being similarly acted on, are more safe in such situations, but there seems no reason to suppose that iron may not be safely used, with due precaution.

82. Instances of dangerous defects in construction, or arising from use, in boilers are but too well attested. The awful explosion on board the steamboat Helen Mc Gregor,§ by which more than thirty persons lost their lives, took effect by forcing off the cast iron head of a wrought-iron boiler, throwing the boiler in the opposite direction: the head was known to be cracked, before the explosion occurred. It is not clearly made out whether this result was produced by a gradual increase of pressure,‖ or by the return to its level of the boat, which had been careened by stopping at a landing place. The steam was not let into the cylinder to propel the engine, when the explosion happened. The boiler was one of six connected boilers of three feet diameter. A cast-iron head should never be united to a wrought-iron boiler with flues,¶ since, independently of the defects to which the metal is liable, the inequality of expansion is very likely to crack it.**

* On both these points see also the remarks of Mr. Lester in Replies to Circular, &c. No. XVII. where the fact is stated both in regard to iron and copper, as resulting from his own experience.

† See Replies to Circular, &c. Nos. II. and XII. Col. S. H. Long and T. Bakewell, Esq. also evidence of Mr. Bramah before Com. of House of Commons, 1817, Dodd's collection.

‡ An instructive description of the action of salt water on iron will be found in the evidence of Professor Faraday before the Com. H. Commons of Eng. on steam navigation, 1822.

§ Nos. III., IV., and XXI., of Replies, &c.

‖ Replies to Circular, No IV.

¶ See also explosion of Atlas, Replies, &c. No. VIII., and No. XXI., Car of Commerce, No. XXI.

** Evidence of John Taylor, Esq. before Com. of House of Commons. A cast-iron boiler-

83. A defect in a wrought iron boiler head, was detected, by one of our correspondents, which we are surprised that any boiler maker should have allowed to pass. In turning the flanches by which the head is riveted to the cylinder, the iron was turned so sharply, as to crack it more than half-way through. This was one of four boiler heads belonging to the same set, found by Mr. E. W. Benton to be unsound. They could not have stood proving.*

There can be no doubt but that the repairs to the boiler of the Caledonia were improperly made,† an iron plate having been fastened upon the boiler with copper rivets: this seems, at least in part, to have been the cause of the accident which subsequently occurred.

84. The idea seems formerly‡ to have been entertained that dangerous explosions could not occur in wrought iron boilers, which were merely rent without doing injury. It is almost needless to remark that the whole tenor of the evidence before the Committee contradicts the idea. Wrought iron may even be separated into fragments, but the great source of danger is in the escape of the hot water, which, with the steam generated by it, produces death in one of its most painful forms.

85. Steam-boilers should not only be proved when originally made, but from time to time, to guard against their gradual wear, or accidental injury; and especially after every important repair made to them. In the intervals care must be secured by other means. These proofs have been recommended by most of our valued correspondents.

86. In the attachment of sheets of metal to each other to form boilers, and in the fixing of heads to boilers, constructors appear to have lost sight of the fact that the metal which is taken out for the rivet-holes weakens the sheet, and that materially. In examining cases of explosion from direct pressure, and where no undue heating or special weakness has led to the result, the lines of rivets appear to determine the direction of the first fracture.§ A very neat example of this was given in the bursting of an iron cylinder in the experiments of the Committee.‖ The head of the cylinder was forced off, carrying with it the metal which projected beyond the line of rivets. The rivet-holes had cut out rather more than half of the circumference of the metal forming the convex surface, along the circle passing through the centres of the rivet-holes, and thus had made the strength of the convex surface to resist rupture in a direction perpendicular to the axis of the cylinder, less than its strength to resist a rupture in the direction of the axis.¶

87. The exposure of joints, formed by the junction of boiler plates, to the fire, may be mentioned as liable to produce very rapid wear. The heat is not conducted off as rapidly as by the other parts of the boiler, and the lower sheet is exposed to rapid oxidation.

88. 3*rd.*—*Appendages to the boiler.* Of these the principal ones have already been made the subject of remark, and recommendation by the

head affixed in his shops to a wrought-iron boiler and originally proved with a pressure of 100 lbs. cracked by heat when only exposed to a pressure of steam of 20 lbs.

* No. VIII. Replies, &c. Boilers of Tally-ho Steamboat.

† Replies, &c. Nos. V., VI., VII., VIII., XXI.

‡ Evidence before Committee of House of Commons. Dodd's Collection.

§ Ewbank on the Explosion of the Boilers of the New England Steamboat. Journ. Frank. Inst. vol. xiii. p. 293.

‖ Report of Committee on Explosions, Part I. p. 67. Journ. Frank. Inst. vol. xvii. p. 224.

¶ With an equal thickness of metal the strength in the former case would have been double that in the latter.

Committee. The forcing pump, as one of the most important, deserves further notice in this place. It is not the intention to recommend any particular form of this pump, especially as the Committee believe that most commonly in use to be entirely adequate to all its objects. They may remark, however, that they consider several valves, between the supply reservoir and the pump, and also between the pump and boiler, as of the greatest importance. They would further recommend to be placed on the eduction pipe a cock similar to that used in locomotive engines. A rod and handle connected with this should be placed in a convenient position, for the engine-man to ascertain, by turning the cock, if the pump is in action. Although this apparatus cannot dispense with due attention to the means of ascertaining the level of the water within a boiler, it may give notice of a defective supply, in time to apply a preventive, instead of a remedy.

89. The Committee consider that their remarks already made in relation to the mode of applying heat to a boiler have been sufficient. They do not see that the use of a fusible metal or fluid bath can be applicable, in practice, to the heating of a steam-boiler, or would, if applicable, realize the advantages which have been claimed for them.

The recommendations embodied in the present division of the subject will be found carried out by the suggestion of appropriate enactments in the project of a law which is appended to this Report.

90. IV. *Carelessness or ignorance of those intrusted with the management of the steam-engine.*

It might be supposed that the fact once known that the engineer or fireman, who, from carelessness, or other cause, allows a boiler under his charge to explode, is in almost every case the first victim of the disaster, would produce care in those intrusted with the engine. But experience shows that this is not so; and the Committee, in proposing remedies, do but the duty which has been confided to them, and proved indispensable by examples, not to be mistaken or disregarded.

91. Familiarity with any sort of danger is so sure to produce callousness to it, and due caution is so apt to be considered as timidity, that a tendency to carelessness must be considered as the natural consequence of the situation of an engineer, or fireman. The subject of the causes of explosions in steam-boilers has been so little investigated, that men well versed in general science might be excused for ignorance of it, and steam-engineers should not therefore be too harshly or hastily blamed for what is incident to the nature of the subject, rather than the fault of the profession. The fact of carelessness or ignorance has however been so much insisted upon by our correspondents* that it must be assumed, and endeavours made to apply a remedy.

92. In the present state of general education in our country it would obviously be impracticable to insist that firemen, or even steam-engineers, should be versed in the scientific principles which regulate the use of steam. The public have, however, a right to expect from employers, that their agents, who are intrusted with human life, should have a thorough practical acquaintance with the steam-engine, and to demand that those who have information of the sources of danger, should lay down plain rules for the guidance of those who have been referred to. As a guard against carelessness, the public have further a right to expect from the higher

* Replies to Circular, &c. Nos. III., VIII., IX., XVII., XIX., XX., XXI., XXIII., XXVIII. Also, Remarks by "an Engineer," Philos. Mag. vol. i. &c. &c.

authorities, beginning with the chief engineers, and rising to the captains of steamboats and masters of shops, that they should exert all the moral influence which vigilance can produce. And from the law, that it should constrain all these, by appropriate penalties, to the discharge of their responsible duties.

This view the Committee have carried out in the project of a law which accompanies their report.

93. V. *Cases of collapse from a partial vacuum within a boiler, or its flues.*

These cases are so little applicable in the state of the steam engine in this country, that the Committee have postponed their discussion until the last.

It is certain that the boiler of a high pressure engine of proper strength for ordinary purposes, would also be able to sustain the action resulting from even the sudden formation of a vacuum within it. Low pressure boilers have been crushed by the pressure of the atmosphere when a vacuum has been formed within.* These accidents are effectually guarded against, as far as experience has shown, by a valve opening inwards with which Watt's boilers were provided.

94. A case of explosion at the Mold Mines, in Flintshire, which has been circumstantially detailed by John Taylor, Esq.,† seems to prove that a rarefaction produced in the interior flues of a high pressure engine, may determine an explosion of the most violent description. The boiler which exploded, belonged to a set of three, feeding the same engine. The fuel used was bituminous coal. The furnace doors of all three of the boilers had been opened and the dampers of two had been closed, when a gust of flame was seen to issue from the mouth of the furnace of these latter, and was immediately followed by an explosion. The interior flue of this boiler was flattened from the sides, the flue and shell of the boiler remaining in their places, and the safety valve upon the latter not being injured. Mr. Taylor states it as probable, that the steam pressure at the time of this accident did not exceed thirty pounds, and that the water was at its proper height. He assigns as the probable cause which determined the collapse of the flue, the ignition of a mixture of gas from the coal with atmospheric air, the contents of the furnace not being carried up the chimney on account of the closing of the damper, by which a partial vacuum was produced. If the strength of the flue was but little more than sufficient to resist a steam pressure of thirty pounds, it is plain that the cause assigned is adequate to have produced the effect. It must be admitted, however, that the testimony of the fireman who escaped injury by the explosion, and who would have been subjected to all the blame of the accident, if any attached, his comrades having been killed, is of that kind which induces a doubt, whether the steam pressure and height of water, were exactly as stated.

The accident, however, suggests the precaution as necessary with coal, and with some kinds of wood, not to close a damper soon after fresh fuel has been added; if the furnace is within the boiler, the injurious effects may be very serious, even more so than in the cases already referred to, where the furnace is not so placed.

95. That a vacuum can occur within a steam-boiler which is in action,

* Arago on Explosions. Annuaire du Bureau des Long. 1830. pp. 148, 169, and 170., also Journ. Frank. Inst. vol. v. pp. 404 and 412.

† On the accidents incident to steam boilers. Philos. Mag. vol. i. see also remarks upon the same by "a practical engineer," and by W. J. Henwood, in the same volume.

as has been propounded within a few years past, is a supposition too palpably contradicted by the facts of the case to require any examination here.

96. VI. Having closed the subject of the means of preventing explosions in steam-boilers, the committee have yet to consider *whether it is possible to provide protection against their effects when they occur.*

The very respectable scientific and practical men who have at different times drawn the attention of the public to this matter, give undoubted authority to the suggestion. The means proposed are, by carrying the passengers in a separate boat from the engine, or by placing the boilers on the guards of the boat, and separating them from the parts occupied by the passengers, by a suitable bulwark.

97. In regard to the first of these plans, it has been attempted, and for want of sufficient patronage by the public, has been laid aside. Public opinion seems to set strongly towards precautions which shall render the engine safe, without crippling its power of giving speed.

98. The larger steamboats on our Atlantic waters have generally the boilers upon the guards,* but without any obstruction between them and the inner parts of the boat. This affords but a partial security, diminishing probably the extent, but not preventing, the destruction of human life. That a bulwark of sufficient strength to protect against explosion, without adding too much to the weight of the boat, can be devised, the Committee are not prepared to assert positively, though they believe that it could.

99. Their views incline entirely to the protection of the hands, as well as passengers by rendering the boiler safe, and they fully believe that this may be done without incumbering the boats now in use, or requiring, in a majority of cases, an entire change of structure in the engine.

They have, however, to meet opinions which they hold in so much respect, introduced a clause in the proposed bill, annexed to this report, by which a bounty is, in fact, offered upon a boat constructed with suitable bulwarks between the interior part, and the boilers.

100. The Committee having now completed their examination of the causes of explosion with their preventives, as far as they are informed upon the subject, and made all the recommendations, which this examination has suggested to them, refer to the accompanying project of a law for the regulations of the boilers and engines of steam-vessels, for the means of carrying the more important of these suggestions into effect.

The provisions of this law refer only to the means of preventing the explosions of boilers of steamboats, or of affording protection against their effects. With the regulations in regard to the navigation or police of the boats, however important, this Committee do not feel warranted in interfering. They believe that the experience necessary to frame such regulations will be found in the appropriate committees of Congress, upon whose attention they would respectfully urge the annexed provisions relating to the engine.

That such an enactment will contribute to the safety of the public,

* We are pleased to see that a boat in which the boilers are placed upon the guards has been put in operation upon the Mississippi. This we trust is only the first of many of this kind to be hereafter constructed.

without interfering injuriously with those interested in the navigation by steam or in the manufacture of the steam-engine, is the deliberate opinion of this Committee.

Respectfully submitted,

In behalf and by direction of the Committee, by

ALEX. DALLAS BACHE,

Chairman of the Com. on Explosions, &c.

Presented to the Board of Managers of the Franklin Institute of Pennsylvania for the Promotion of the Mechanic Arts, and approved, September 21st, 1836.

M. W. BALDWIN,

Chairman of the Board of Managers.

WILLIAM HAMILTON,

Actuary.

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A BILL

FOR THE REGULATION OF THE BOILERS AND ENGINES OF VESSELS PROPELLED IN THE WHOLE OR IN PART BY STEAM.*

SECTION 1.†—*Be it enacted by the Senate and the House of Representatives of the United States of America, in Congress assembled,* That it shall be the duty of all owners of steamboats, or vessels propelled in the whole, or in part, by steam, on or before the —— day of ——, one thousand eight hundred and ——, to make a new enrolment of the same under the existing laws of the United States, and to take out from the collector or surveyor of the port, as the case may be, where such steamboat or vessel is enrolled, a new license, under such conditions as are now imposed by law, and as shall be imposed by this act.

SEC. 2.‡—*And be it further enacted,* That it shall not be lawful for the owner, master, or captain, of any steamboat or vessel propelled in the whole or in part by steam, to transport any goods, wares, and merchandise, or passengers, in, or upon the bays, lakes, rivers, or other navigable waters of the United States, from and after the said —— day of ——, one thousand eight hundred and ——, without having first obtained from the proper officer, a license under the existing laws, and without having complied with the conditions imposed by this act; and for each and every violation of this section, the owner or owners of said steamboat, or vessel, shall forfeit and pay to the United States the sum of ——.

SEC. 3.§—*And be it further enacted,* That it shall be the duty of the President to appoint at such ports on the navigable waters, bays, lakes, and rivers, of the United States, as in his judgment will be most convenient to the owners and masters of steamboats, and vessels propelled in the whole or in part by steam, one or more persons who shall be practical mechanics, of competent skill, to make inspections of the boilers and machinery employed in such boats and vessels, whose duty it shall be to make such inspections, when called upon for that purpose, to give to the owner or master of such boat or vessel, duplicate certificates of all such inspections, and the said person, so appointed, shall, before entering upon the duties of said appointment, take an oath, before some competent authority, faithfully to discharge and perform the same.

SEC. 4.—*And be it further enacted,* That the owner, master, or captain of each and every boat or vessel propelled in the whole or in part by steam, shall certify, to said inspector the greatest pressure, or total elastic force, of the steam intended to be produced in the boiler, which certificate shall regulate in the proofs, trials, and construction, hereinafter required.

* The sections of this bill which are taken from that reported by the Committee on Naval Affairs, in the Senate of the United States, at the session of 1835-6, are marked by a note of reference to the sections of the latter.

† Sect. 1 of the bill reported in Senate U. S.

‡ Sect. 2 of bill, &c.

§ From sect. 3 of the bill reported, &c.

SEC. 5.—*And be it further enacted*, That each and every boiler of a steamboat, or vessel propelled in the whole or in part by steam, shall be constructed, and arranged, so as to comply with the following provisions:

1. There shall be two safety-valves, each of which shall be competent to discharge the steam made in the ordinary working of the boiler.

2. The first of said valves shall be graduated by the maker of the engine, and have stamped upon the lever, by which it is weighted, the pressure at which it will by calculation open, when the appropriate moveable weight is placed at the several marks. Said pressure to be the difference between the pressure of the steam within, and atmospheric pressure on said valve.

3. When the moveable weight exerts its greatest pressure, the total pressure upon said valve shall not exceed the pressure as certified according to the provision of the fourth section of this act.

4. The second of said valves, denominated the lock-up valve, shall be immoveably weighted, the total pressure upon it not to exceed said certified pressure.

5. Said lock-up valve, with its lever and other attachments, shall be inclosed in a grated box, or otherwise duly arranged so that it can be raised, but not pressed down, except as above provided, upon its seat.

6. Said inclosure, or arrangements, shall be secured with a lock, of which the captain or master of said boat shall alone have the key.

7. Said inclosure, or arrangements, shall admit a rise in the valve of at least one-fourth of the diameter of its seat.

8. The lever of said valve shall be so constructed as on the rising of the valve, to diminish the effect of the acting weight, by at least one-tenth of the ordinary pressure derived from said weight.

9. When two boilers, each of not more than forty inches diameter, are connected by a steam-pipe, each pair of said boilers may be furnished with safety-valves, as described in this section, for a single boiler.

10. When the certified pressure provided in section fourth, does not exceed two atmospheres, each and every boiler shall be furnished with a mercurial-gauge, indicating by a float or rod, upon a duly graduated and marked scale, the excess of pressure within the boiler over atmospheric pressure, in inches of mercury.

11. Said gauge and scale shall be so placed as to be readily examined by any and every passenger on board of said boat.

12. Each and every boiler shall be provided with a fusible metal apparatus of suitable form and dimensions, to be applied to the boiler itself, or to its flues, at the place which may be considered that of greatest heat, or most liable to exposure from a deficient supply of water.

13. Said fusible metal shall be contained in a tube to prevent its exposure to pressure, and shall on softening, communicate an alarm by some suitable device.

14. Said apparatus shall be duly secured from being rendered ineffective, in the manner of the lock-up safety-valve heretofore provided.

15. The fusible metal herein before referred to, shall be compounded by the inspector, who shall place it in the apparatus as aforesaid, and shall satisfy himself that the whole is duly arranged as heretofore prescribed; for which service he shall receive, on certifying the same, a compensation of ——.

16. The said alloys shall be compounded according to the certified pressure of steam within the boiler, by the following table of parts, by weight, of the ingredients:—

TABLE OF ALLOYS FOR USE IN CLOSED TUBES, AND WITH A METALLIC STEM.

Certified pressure in atmospheres.	Tin.	Lead.	Bismuth.	Certified pressure in atmospheres.	Tin.	Lead.	Bismuth.	Certified pressure in atmospheres.	Tin.	Lead.	Certified pressure in atmospheres.	Tin.	Lead.
1½	8	8	7.5	4	8	8	3.4	8	8	8.0	12	8	12.3
2	8	8	6.2	5	8	8	2.2	9	8	9.8	13	8	13.2
2½	8	8	5.3	6	8	8	1.2	10	8	10.6			
3	8	8	4.6	7	8	8	0.5	11	8	11.4			

SEC. 6.—*And be it further enacted*, That before delivering the certificate hereinafter to be provided for, the inspector, heretofore provided, shall examine the apparatus required by section fifth, and shall ascertain that all the provisions of that article are complied with.

SEC. 7.—*And be it further enacted*, That any person or persons whatsoever who shall wilfully overload or otherwise render inoperative said safety-valve or valves, or render ineffective said mercurial-gauge or gauges by plugging up or stopping off, or in any other manner preventing their action, or shall in any manner, impair, or interfere, with the usefulness of said fusible metal apparatus, shall for every offence be subject to the penalty of —— dollars, and to an imprisonment at the discretion of the court, not to exceed ——, and in case of accident to said steam-boiler, resulting from said offence, by which life is lost, shall be deemed to have been guilty of manslaughter, and punished according to law for said offence.

SEC. 8.—*And be it further enacted*, That not more than two boilers of a boat, or vessel propelled in the whole or in part by steam, and those immediately contiguous, shall have connected water pipes, nor shall the license heretofore provided for, be issued until the inspector has satisfied himself, and has certified, that the provision of this section is complied with.

SEC. 9.—*And be it further enacted*, That for each and every bursting of the boiler of a steamboat or vessel propelled in the whole, or in part, by steam, which shall occur from a deposite of sedimentary matter within a boiler, the master of said vessel, shall forfeit the sum of ——— dollars; and that in case life shall be lost by the same, he shall be deemed to have been guilty of manslaughter, and shall be liable to prosecution accordingly.

SEC. 10.—*And be it further enacted*, That no boat or vessel propelled in the whole or in part by steam shall be licensed until the inspector has certified on examination, that no part of the boiler of said boat is ordinarily directly exposed to flame, or to heated air from the draught, without the immediate contact of water.

SEC. 11.*—*And be it further enacted*, That it shall be the duty of the person who shall be called upon to inspect the boilers and machinery of any steamboat or vessel, in conformity to the provisions of this act, carefully, fully, and thoroughly, to inspect and examine the engine and machinery of said boat or vessel, and to state his opinion of their soundness: and he shall, moreover, provide himself with a suitable hydraulic pump, and, after examining into the state and condition of the boiler, or boilers, of said boat, or vessel, it shall be his duty to test the strength and soundness of said boiler, or boilers, by applying to the same a hydraulic pres-

* Sec. 5 of the bill reported in the Senate of U. S. with slight verbal changes.

sure equal to three times the certified pressure which the boilers are to carry in steam; and if he shall be of opinion, after such examination and test, that the said machinery and boilers are sound and fit for use, he shall deliver to the owner or master of said vessel or boat, duplicate certificates to that effect, stating therein the age of said boilers, and the pressure of steam which may be carried by them, and which shall in no case exceed one-third part of the proof-pressure, one of which certificates it shall be the duty of said master or owner, to deliver to the collector or surveyor of the port, whenever he shall apply for license or for renewal of license: the other he shall, under a penalty of —— hundred dollars for every day that he shall neglect so to do while the boat is running, cause to be posted up, and kept in some conspicuous part of the boat or vessel, for the information of the public, and for each and every inspection of the said machinery, and inspection and test of the said boiler or boilers, the said inspector shall be allowed and paid by the owner or master thereof, and before the delivery of said certificates, the sum of —— dollars.

SEC. 12.*—*And be it further enacted*, That it shall be the duty of the owners or masters of said boats or vessels, to cause the examination of the machinery, and the examination and test of the boilers, as provided in the sections of this act, to be made, at least, once in every six months; and to deliver to the collector or surveyor of the port where such boat or vessel, has been enrolled or licensed, the certificate of such inspection; and on failure thereof, he or they, shall forfeit the license granted to such boat or vessel, and be subject to the same penalty as though he had run the said boat or vessel, without having obtained such license.

SECT. 13.†—*And be it further enacted*, That whenever the master of any boat, or vessel, or the person, or persons, charged with the navigating said boat or vessel which is propelled in the whole or in part by steam, shall stop the motion, or headway, of said boat, or vessel; or the said boat, or vessel, shall be stopped for the purpose of discharging, or taking in cargo, fuel, or passengers; he, or they, shall keep the engine of said boat, or vessel, in motion sufficient to work the pump, and give the necessary supply of water, under the penalty of ——— dollars for each and every offence in neglecting or violating the requirements of this section.

SEC. 14.‡—*And be it further enacted*, That no other than a practical mechanic who shall be of the age of twenty-one years, or upwards, shall have served two years in a steam engine factory, or general machine making establishment, and who shall have a thorough knowledge of the working of an engine, and shall produce satisfactory testimonials of steady habits, shall be employed as an engineer on board of any boat or vessel propelled in whole or in part by steam, provided that for every violation of this section, the owners or master of said boat or vessel shall forfeit the sum of —— dollars.

SEC. 15.§—*And be it further enacted*, That for every explosion which shall happen from any cause whilst the captain, master, or engineer shall be engaged in gambling, or attending to any game of chance, or hazard, or shall be intoxicated, or which shall happen from racing, or from carrying higher steam than the quantity authorized by the certificate, the owner

* From Sec. 6 of the law reported in the Senate of U. S., the period for making the inspections of the boilers, &c., is here proposed to be extended to six months.

† From Sec. 7 of the bill reported in the Senate, &c.

‡ The Committee propose this section as a substitute for the 16th section of the bill reported in the Senate. That section requiring an examination of engineers by the inspectors.

§ From Sect. 13th of the bill reported, &c.

of such steamboat, or vessel shall be subject to the penalties provided for in the sixteenth section of this act: and the captain, master, or engineer shall be respectively subject to the penalties hereafter provided in the seventeenth section of this act.

SEC. 16.*—*And be it further enacted*, That any owner or master, of any steamboat, or vessel, propelled in the whole or in part by steam, who shall fail to obtain, or neglect to renew, the certificates of examination hereinbefore provided for in the several sections of this act, shall be barred from the recovery of any claim for freight or insurance that may accrue when without said certificate, and should any loss or damage to property, or injury to persons, in such case occur in consequence of the breaking of any part of the machinery, or bursting of the boiler, or boilers, the owner shall be responsible to the full amount of said loss, damage, or injury.

SEC. 17.†—*And be it further enacted*, That the captain or master of any boat or vessel propelled in the whole or in part by steam, which may not have been examined, and obtained the certificates required by the several sections of this act, shall in the event of loss or damage to property, or injury to persons, occasioned by the breaking of any part of the machinery, or the bursting of the boiler, or boilers, be subject to a fine of not less than ——— nor more than ——— dollars, and an imprisonment of not less than ———, nor more than ———; and that in event of loss of life being the result of such accident, then said captain, or master, shall be adjudged guilty of manslaughter.

SEC. 18.—*And be it further enacted*, That any boat or vessel propelled in the whole or in part by steam, which shall have its boilers upon the guards of the boat, and shall have between them, and the interior of the boat, or vessel, a sufficient bulwark of timber, or other suitable material, so that passengers shall be protected effectually from injury in the event of explosion, shall be, on a certificate to the foregoing effect from the inspector heretofore provided, exempted from the payment of fees for the taking out of the license of navigation, and shall have remitted one half of the fees for proving and for other purposes of precaution heretofore provided. The fees remitted in such case to be assumed and paid to the respective officers by the United States.

SECT. 19.‡—*And be it further enacted*, That for any false certificate, or one given without the thorough examination contemplated by this act, the inspector herein provided shall be dismissed from office, and fined not less than ——— dollars, nor more than ——— dollars, and imprisoned not less than ———, nor more than ———; and shall be incapable of ever being re-appointed to said office.

SEC. 20.§—*And be it further enacted*, That all penalties, fines and forfeitures imposed by this act, may be sued for and recovered in any court of the United States of competent jurisdiction within the district, or circuit, where the same may have been incurred, in the name of the United States—one half to the use of the informer, and the other half to the use and benefit of the United States.

Provided, That all suits, actions, or indictments instituted, commenced, or found, under this act, shall be commenced or found within two years after the offence has been committed, or the cause of action accrued.

* From Sect. 11th of the bill, &c.
† From Sect. 12, of the bill, &c.
‡ Sect. 17th of bill reported, &c.
§ Sect. 18th of bill, &c., with the addition of the proviso at the close of the section.